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Volume II

AN IN-FLIGHT INVESTIGATION TO DEVELOP CONTROL SYSTEM DESIGN CRITERIA FOR FIGHTER AIRPLANES

Volume II Appendices I through V

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CORNELL AERONAUTICAL LABORATORY, INC.

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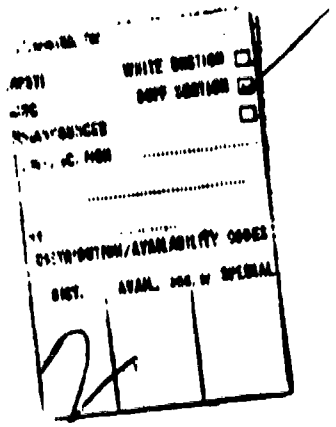

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FOREWORD

This report was prepared for the United States Air Force by the Cornell Aeronautical Laboratory, Inc. (CAL), Buffalo, New York in partial fulfillment of Contract No. F33615-69-C-1664, and describes the results of the first flight program under that contract.

The investigation reported here was performed by the Flight Research Department of CAL under sponsorship of the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio, as part of Project 8219, Task 821905. The Air Force Project Engineer was Mr. David K. Bowser (FGC).

This report represents the combined efforts of many members of the Flight Research Department. Fred D. Newell is the program manager for the overall variable stability T-33 program. Ronald W. Huber is responsible for modifications, calibration, and maintenance of the T-33 variable stability system. The CAL project engineer for this investigation was T. Peter Neal, and the assistant project engineer was Rogers E. Smith. The evaluation pilots were G. Warren Hall (Pilot W), and T. Michael Harris (Pilot M). Rogers E. Smith, Robert P. Harper, Jr., and Nello L. Infanti acted as safety pilots on the evaluation flights. The engineering assistance of Alan B. Adler, James R. Lyons, and C. Macey Poppenberg is also gratefully acknowledged.

This report was submitted by the authors in June 1970.

This report has been reviewed and is approved.

C. B. Westbrook
Chief, Control Criteria Branch
Air Force Flight Dynamics Laboratory

ABSTRACT

The effects of control system dynamics on the longitudinal flying qualities of fighter airplanes were investigated in flight, using the USAF/CAL variable stability T-33 airplane. Two pilots evaluated a total of 57 different combinations of control-system and short-period dynamics at two flight conditions, while performing tasks representative of the "combat" phase of a fighter's mission. The pilot rating and comment data from this investigation indicate that the dynamic modes of the flight control system can cause serious flying qualities problems, even if the short-period mode is well behaved. The data do not correlate with the control system requirements of MIL-F-8785B. In addition, the data demonstrate that the C* criterion does not adequately account for the effects of control system dynamics. Pilot-in-the-loop analysis of the data is shown to describe effectively the pilot's difficulties in control of pitch attitude, providing insight into how the pilot flies the airplane. A design criterion, based on this analysis, is shown to be applicable to a wide range of short-period and control-system dynamics. A simplified version is also presented to provide the designer with preliminary estimates of flying qualities. Volume I contains the body of the report, while Volume II consists of the Appendices.

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LIST OF ILLUSTRATIONS

LIST OF SYMBOLS

a_e	Equivalent time delay (sec)
BW	Bandwidth; the frequency at which the phase angle of the Φ/θ_c transfer function = -90 deg (rad/sec)
$(BW)_{min}$	The value of the closed-loop bandwidth which the pilot is trying to achieve in precision tracking tasks (rad/sec)
c	Wing mean aerodynamic chord (ft)
C_L	$= \frac{L}{\bar{q}S}$, Airplane lift coefficient
C_{L_α}	$= \frac{\partial C_L}{\partial \alpha}$ (1/rad)
$C_{L_{\delta_e}}$	$= \frac{\partial C_L}{\partial \delta_e}$ (1/rad)
C_m	$= \frac{M}{\bar{q}Sc}$, Airplane pitching moment coefficient
C_{m_α}	$= \frac{\partial C_m}{\partial \alpha}$ (1/rad)
$C_{m_{\dot{\alpha}}}$	$= \frac{\partial C_m}{\partial \left(\frac{\dot{\alpha}\bar{c}}{2V_T}\right)}$ (1/rad)
C_{m_q}	$= \frac{\partial C_m}{\partial \left(\frac{qc}{2V_T}\right)}$ (1/rad)
$C_{m_{\delta_e}}$	$= \frac{\partial C_m}{\partial \delta_e}$ (1/rad)
C^*	Particular blend of the airplane's n , $\dot{\phi}$ and $\dot{\theta}$ responses (g's) (Reference 15)
dB	Decibel units for Bode amplitude, where amplitude in dB = $20 \log_{10}$ [amplitude]
$\left(\frac{dA}{d\chi}\right)_{ad}$	Rate of change of Bode amplitude with phase for the airplane plus pilot time delay at $\omega = (BW)_{min}$ (dB/deg)
F_{AS}	Aileron stick force, positive to the right (lb)
F_{RP}	Rudder pedal force, positive for right rudder (lb)
F_S	Elevator stick force, positive for a pull (lb)
$\frac{F_S}{n}$	Steady-state stick force per unit normal acceleration change, at constant speed (lb/g)
$\frac{F_S}{\theta_e}$	Transfer function of the pilot model

g Acceleration of gravity (ft/sec^2)

h_d Density altitude (ft)

h_p Pressure altitude (ft)

I_y Moment of inertia about airplane y axis ($slug\text{-}ft^2$)

$K_{\theta W}$ Pilot gain at ω $(BW)_{min}$ (lb/deg)

K_L Total closed-loop gain, $K_L = K_p K_\theta$ (1/sec)

K_p Steady-state pilot gain (lb/deg)

K_θ Gain of airplane's θ/F_s transfer function $\left(\frac{deg/sec}{lb}\right)$

K'_θ Gain of airplane's θ/δ_s transfer function $\left(\frac{deg/sec}{in}\right)$

ℓ_p Distance of the pilot's station ahead of the center of gravity (ft)

L Airplane lift, positive for positive angles of attack (lb)

L_α - $\frac{\bar{q}SC_{L_\alpha}}{mV_T}$ (1/sec)

L_{δ_e} - $\frac{\bar{q}SC_{L_{\delta_e}}}{mV_T}$ (1/sec)

m Mass of airplane (slugs)

M Airplane pitching moment, positive nose up (ft-lb)

M_α - $\frac{\bar{q}\,Sc\,C_{m_\alpha}}{I_y}$ ($1/sec^2$)

$M_{\dot{\alpha}}$ $\frac{\bar{q}\,S\left(\frac{c^2}{2V_T}\right)C_{m_{\dot{\alpha}}}}{I_y}$ (1/sec)

M_q $\frac{\bar{q}\,S\left(\frac{c^2}{2V_T}\right)C_{m_q}}{I_y}$ (1/sec)

M_{δ_e} $\frac{\bar{q}\,Sc\,C_{m_{\delta_e}}}{I_y}$ ($1/sec^2$)

n Normal acceleration at c.g., positive for a pull up (g's) ($n = 1$ for level flight)

$\frac{n}{\alpha}$ Steady-state normal acceleration change per unit angle-of-attack change, when the airplane is maneuvered at constant speed (g's/radian) $n/\alpha \approx \frac{V_T}{g}\frac{1}{\tau_{\theta_2}}$

P_E = $\frac{2\pi}{\omega_E}$, Period of equivalent short-period mode (sec)

$\bar{q}$ = $\frac{1}{2}\rho V_T^2$, Dynamic pressure (lb/ft^2)

q Airplane pitch rate about y body axis. For wings-level flight $q = \dot{\theta}$

s Laplace operator (1/sec)

S Wing area (ft^2)

t Time (sec)

T_p Phugoid period (sec)

V_{ind} Trimmed indicated airspeed, (knots)

V_T Trimmed true airspeed (ft/sec)

α Airplane angle of attack, positive for relative wind from below (rad)

β Airplane angle of sideslip, positive for relative wind from right (rad)

δ_{AS} Aileron stick deflection at grip, positive to the right (inches)

δ_e Airplane elevator deflection, positive trailing edge down (rad)

δ_{RP} Rudder pedal deflection, right rudder is positive (inches)

δ_s Elevator stick deflection at grip, positive aft (inches)

$\left(\frac{\delta_e}{F_s}\right)_{ss}$ Steady-state gearing between elevator deflection and elevator stick force (rad/lb)

$\left(\frac{\delta_e}{\delta_s}\right)_{ss}$ Steady-state gearing between elevator deflection and elevator stick displacement (rad/in.)

ζ_d Dutch-roll damping ratio

ζ_E Equivalent short-period damping ratio

ζ_p Phugoid damping ratio

ζ_{sp} Short-period damping ratio

ζ_s Damping ratio of second-order control system lag

ζ_ϕ	Damping ratio of second-order numerator term in bank-angle-to-aileron transfer function
θ	Airplane's pitch attitude with respect to horizon, positive nose up (deg or rad)
θ_c	Commanded change in airplane pitch attitude (deg or rad)
θ_e	$(\theta_c - \theta)$, Error between the commanded pitch attitude and the airplane pitch attitude (deg or rad)
$\frac{\theta}{F_s}$	Constant-speed transfer function of θ to F_s for airplane plus control system
$\frac{\theta}{\theta_e}$	Open-loop transfer function of airplane plus control system plus pilot
$\left(\frac{\theta}{\theta_e}\right)^*$	$\frac{\theta}{\theta_e}$ transfer function with uncompensated pilot ($F_s/\theta_e = K_p e^{-0.3s}$)
$\frac{\theta}{\theta_c}$	Closed-loop transfer function of airplane plus control system plus pilot
$\left\lvert\frac{\theta}{\theta_c}\right\rvert_{max}$	Magnitude of resonant peak in the θ/θ_c Bode amplitude plot (dB)
$\left\lvert\frac{\ddot{\theta}}{F_s}\right\rvert_{max}$	Maximum Bode amplitude of $\ddot{\theta}/F_s$ $\left(\frac{rad/sec^2}{lb}\right)$
ρ	Air density (slug/ft^3)
σ	Real part of $s = \sigma + j\omega$
τ_1	Time constant of control system lead element (sec)
τ_2	Time constant of control system lag element (sec)
τ_e	Equivalent lead time constant of airplane (sec)
τ_{θ_1}	Time constant of pilot's lead element (sec)
τ_{θ_2}	Time constant of pilot's lag element (sec)
τ_R	Roll mode time constant (sec)
τ_s	Spiral mode time constant (sec)
τ_{θ_2}	Airframe lead time constant in θ/F_s transfer function (sec)
$\lvert\phi/\beta\rvert_d$	Absolute value of control-fixed roll-to-sideslip ratio evaluated at $\omega = \omega_d$

ω	Bode frequency (rad/sec)
ω_c	Gain crossover frequency, where the open-loop Bode amplitude curve crosses 0 dB line (rad/sec)
ω_d	Dutch roll undamped natural frequency (rad/sec)
ω_e	Undamped natural frequency of equivalent short-period mode (rad/sec)
ω_{sp}	Short-period undamped natural frequency (rad/sec)
ω_s	Undamped natural frequency of second-order control system lag (rad/sec)
ω_ϕ	Undamped natural frequency of second-order numerator term in bank-angle-to-aileron transfer function (rad/sec)
$\lvert\ \rvert$	Signifies Bode amplitude of a transfer function
$\angle$	Signifies Bode phase angle of a transfer function
$\angle_{ad}$	Phase angle of the airplane plus pilot time delay at $\omega = (BW)_{min}$ (deg)
$\angle_{pc}$	Phase angle of the pilot compensation at $\omega = (BW)_{min}$ (deg)
$\dot{(\ )} = \frac{d}{dt}(\ )$	First derivative with respect to time
$\ddot{(\ )} = \frac{d^2}{dt^2}(\ )$	Second derivative with respect to time

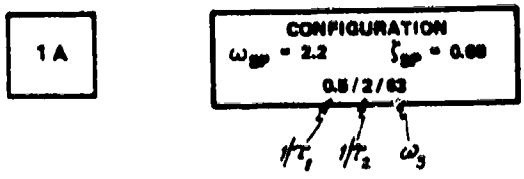
ABBREVIATIONS

FCS	Flight control system
CAL	Cornell Aeronautical Laboratory, Inc.
c.g.	Center of gravity
HOS	Higher-order-system program (Reference 6)
IFR	Instrument flight rules
log	Logarithm to base 10
norm.	Normalized
PIO	Pilot-induced oscillation
PIOR	Pilot-induced-oscillation rating
PR	Pilot rating (Cooper-Harper scale)
USAF	United States Air Force
VFR	Visual flight rules

APPENDIX I

PILOT COMMENTS, BODE PLOTS, TIME HISTORIES FOR EACH CONFIGURATION

Summaries of all the pilot comments and ratings, as well as the pertinent open and closed-loop parameters, are presented in this appendix for each configuration simulated in this experiment. The open and closed-loop pitch-attitude Bode characteristics and time histories are shown on the opposite page to the summarized pilot comments for each configuration. Each configuration is identified by its number/letter identifier, for example 1A. The block at the top of the pilot comment page identifies the control-system and short-period dynamics for the configuration. For example:



Note that a dash (-) indicates that $1/\tau_1$ or $1/\tau_2$ is ∞, i.e., the lead or lag term is not present. The block at the top of the page with the Bode characteristics and the time history plots for each configuration contains the pertinent flight condition and closed-loop analysis parameters. For clarity, the units are not included in the blocks but are given in the List of Symbols.

The pilot comment summaries were prepared from transcription of the recorded comments made by the pilot during each evaluation with reference to the Pilot Comment Card discussed in Section 4.2. Referring to the comment card, the pilot comments under the specific headings of "ability to trim", "stick motions", and "lateral-directional control" indicated that none of these areas was a factor in the evaluations, and therefore those comments are not included in the summaries. Comments on "longitudinal control in steep turns" were generally the same as those for "normal acceleration control" and were deleted from the summaries. There was a difference between the two evaluation pilots in their interpretation of what was asked for under the specific heading of "special piloting techniques"; and therefore, to avoid confusion, these comments are also not shown in the summaries.

There are 7 evaluations in the experiment, each marked by an asterisk on the flight number at the top of the pilot comment summary, which are not used in the data analysis. Justification for this decision is based on the following factors. Each of these evaluations was performed early in the experiment and both the comments and ratings are appreciably less severe

than for the repeat evaluations of the configuration. The incompatibility of these evaluations with later repeats is probably attributable to the pilots not organizing the evaluation tasks early in the program, so that bad characteristics were sometimes overlooked. There are other evaluations in the experiment that appear inconsistent with the trend of pilot opinion within a given group of configurations, but in these cases no clear justification exists for not including the results in the data analysis.

In the presentation of the open and closed-loop Bode characteristics, for each configuration, three transfer functions are of interest: θ/F_s, θ/θ_c and θ/θ_e. The following diagram, representative of the closed-loop pitch-attitude tracking task, can be used to understand these transfer functions.

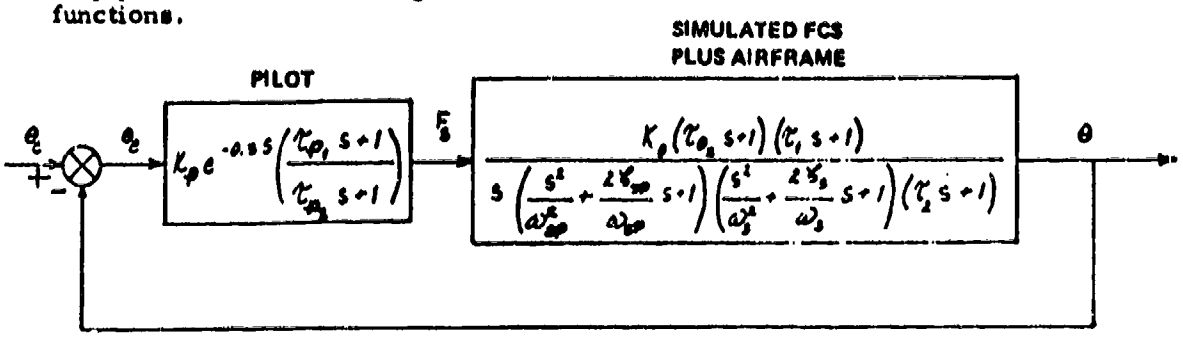


Figure I-1 Block Diagram of Closed-Loop Pitch-Attitude Tracking

When interpreting the Bode plots, the following should be noted:

(1) θ/F_s is the open-loop transfer function of the airplane plus control system.

θ/θ_e is the open-loop transfer function of the airplane plus control system plus pilot.

θ/θ_c is the closed-loop transfer function of the airplane plus control system plus pilot.

(2) The terms "open-loop" and "closed-loop" are meant to apply to the block diagram shown in Figure I-1. Any FCS loops around the airframe are always assumed to be closed when computing the θ/F_s characteristics.

(3) In the calculation of the Bode amplitude plots for θ/F_s, a nominal F_s/n = 5 lb/g was used, and the units of $|\theta/F_s|$ prior to conversion to dB were deg/lb. (Note that $K_\rho = 57.3g/[V_T(F_s/n)]$). The Bode plots for the other two transfer functions were taken directly from the pilot-compensated Nichols chart overlays.

(4) The pilot lead compensation was somewhat arbitrarily restricted to $\angle_{pc}$ = + 80 deg for the analysis because values greater than + 80 deg do not significantly improve the closed-loop performance. This restriction on $\angle_{pc}$ reduced the BW achieved for Configurations 1G and 6F and reduced the low-frequency droop for Configurations 1F, 1G, 6F, and 7H.

(5) The values of K_P, K_{BW}, and K_L were determined by the methods explained in Sections 6.9 and 7.4.

Two pitch-attitude time histories for each configuration are shown in the lower left-hand plot. The first time history (solid line) represents the normalized open-loop θ response to an F_s impulse input, for the airplane plus control system. This time history also represents the $\dot{\theta}$ response to an F_s step input. The second time history (dashed line) represents the normalized open-loop θ response to a θ_c impulse input, for the airplane plus control system plus pilot. The purpose of this time history is to show the effects of the pilot time delay plus the lead or lag compensation determined using the closed-loop analysis.

The lower right-hand plot for each configuration shows the normalized closed-loop θ response to a step θ command (θ_c). This closed-loop time history was generated by mechanizing the closed loop of Figure I-1 on an analog computer. The pilot's 0.3 sec delay time was simulated using a fourth-order Padé approximation of $e^{-0.3s}$. This closed-loop time history complements the frequency-response plots and gives a complete picture of the closed-loop pitch-attitude tracking problems predicted for each configuration.

1 A

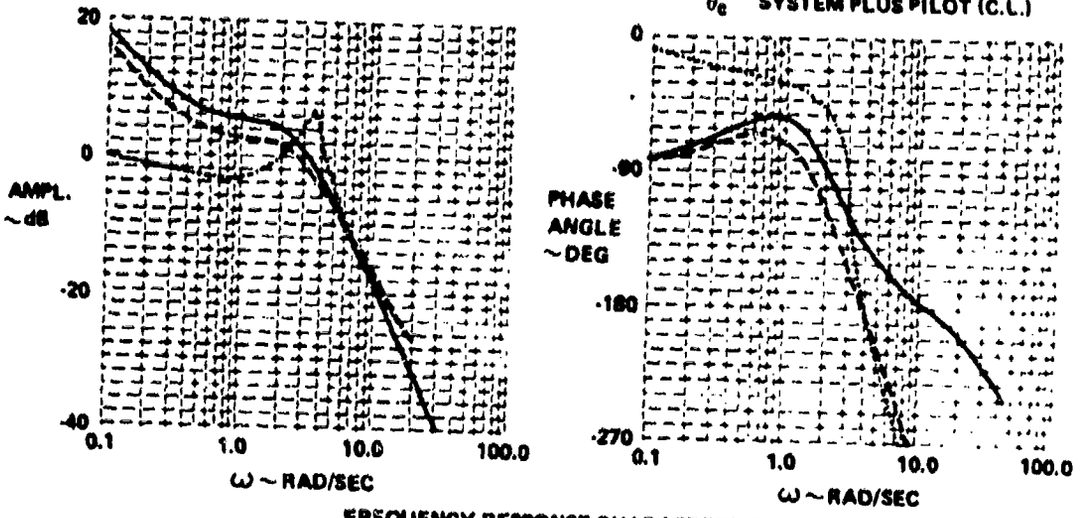
CONFIGURATION
$\omega_{sp} = 2.2$ $\zeta_{sp} = .69$
0.5/2/82

FLT/PILOT	1082[a]/RE	1084/RE	1081/RB	1083[a]/RE	1073/[illegible]
PR/PIOR	2/1	6/2.5	4/1.5	2/1	5/2
F_s/n AVE g	10.0/0.27	7.3/0.53	7.3/0.53	6.8/0.65	7.3/0.53
K_p/K_{pm}	2.2/2.3	1.1/1.2	1.1/1.2	0.91/0.98	1.1/1.2
STICK FORCES	LIGHT BUT STILL VERY GOOD ON TARGET	QUITE LIGHT. WOULD HAVE PREFERRED HEAVIER FORCES BUT GEARING WAS LIMITED ON THIS FLIGHT AT THE VALUE CHOSEN. SHOULD HAVE BEEN 20-30% HEAVIER.	LIGHT, HEAVIER FORCES WERE NOT ALLOWED FOR THIS VERY RESPONSIVE AIRPLANE.	LIKED THE STICK FORCES	O.K. HEAVIER FORCES SEEMED TO HELP THIS CONFIGURATION
PREDICTABILITY OF RESPONSE	GOOD, NICE SNAPPY INITIAL RESPONSE, PREDICTABLE FINAL RESPONSE.	NOT VERY GOOD. INITIAL RESPONSE VERY RAPID AND FINAL RESPONSE IS NOT PREDICTABLE. CONSISTENTLY OVERSHOOT ANY TARGET.	NOT TOO BAD. ALWAYS HAVE ONE OVERSHOOT IN PITCH ATTITUDE. JUST ANNOYING.	QUITE GOOD. INITIAL RESPONSE GOOD, AND FINAL RESPONSE PREDICTABLE	NOT GOOD. INITIAL RESPONSE IS SATISFACTORY BUT THEN RESPONSE TAKES OFF. SO FINAL RESPONSE IS NOT PREDICTABLE
ATTITUDE CONTROL/ TRACKING CAPABILITY	GOOD. SLIGHT OSCILLATIONS, BUT A GOOD AIRPLANE. GOOD ON TARGET, GOOD TRACKING	POOR, OVERCONTROLLING TENDENCY. NO PIO TENDENCY. CAN EVENTUALLY SETTLE DOWN ON TARGET BUT FEELS LIGHT ON TARGET. NOT SOLID	NOT STEADY ON TARGET. CAN GET THERE EASIER THAN YOU CAN KEEP IT THERE. WANTS TO WANDER ALL THE TIME.	GOOD	NOT VERY GOOD. DIFFICULT TO ACQUIRE A TARGET. THEN WANDERS OFF TARGET. RAPID PULSE TYPE INPUTS WORKED BEST
NORMAL ACCELERATION CONTROL	GOOD, SOME SMALL OSCILLATIONS ON TARGET BUT REALLY VERY GOOD INDEED.	NOT VERY GOOD. OSCILLATES ±0.3 TO 0.4. G ABOUT THE DESIRED G LEVEL. JUST MANEUVERING YOU CAN PULL G WITHOUT THE OSCILLATIONS.	EASY TO OVERSHOOT G DUE TO LIGHT FORCES.	GOOD	TENDENCY TO OVERCONTROL
EFFECTS OF RANDOM DISTURBANCES	DIDN'T SHOW ANYTHING	DID NOT SEE THE EXPECTED DEGRADATION DUE TO RN DISTURBANCES. THERE WAS A PROBLEM BUT NOT AS BAD AS EXPECTED	NO PROBLEM	NOTHING NEW	NO PROBLEM
IFR PROBLEMS	EASIER TO FLY IFR. DISCRETE ERROR TRACKING TASK WAS EASY TO DO	SOME PIO TENDENCY ON THE D.E. TRACKING TASK AND RN TRACKING TASK, BUT NOT CONSIDERED TO BE A REAL PROBLEM	LIGHT FORCES LEAD TO A PROBLEM WITH D.E. TRACKING TASK. TENDED TO OVERSHOOT AND OSCILLATE.	NO NEW PROBLEMS	NOTHING NEW. D.E. TRACKING TASK SHOWED UP TENDENCY TO OVERSHOOT
GOOD FEATURES	THIS IS A GOOD FIGHTER AIRPLANE, WELL BEHAVED ON TARGET, LIGHT, COMFORTABLE STICK FORCE PER G.	NICE LIGHT FORCES.	VERY MANEUVERABLE	PREDICTABLE, GOOD RESPONSE TO CONTROL INPUTS	COULD MANEUVER THE AIRPLANE BUT NOT AS WELL AS DESIRED
OBJECTIONABLE FEATURES	NO MAJOR OBJECTIONS. MINOR OVERSHOOTS AND OSCILLATIONS.	DIFFICULT TO ACQUIRE A TARGET. THE INITIAL PITCH RESPONSE SEEMS VERY RAPID AND FINAL RESPONSE IS OSCILLATORY. FORCES ARE A BIT TOO LIGHT	STICK FORCES TOO LIGHT. DIDN'T FEEL ADEQUATE STRUCTURAL PROTECTION EXISTED. NOT STEADY ON TARGET. MAIN COMPLAINT	NONE	MINOR TYPE OBJECTIONS. TENDENCY TO WANDER OFF TARGET AND TO OVER G

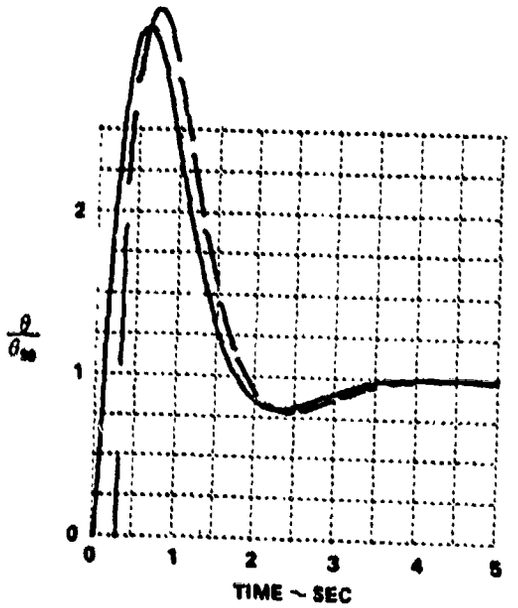
[a] RATINGS NOT USED IN DATA ANALYSIS. SEE DISCUSSION AT THE BEGINNING OF THIS APPENDIX

1 A

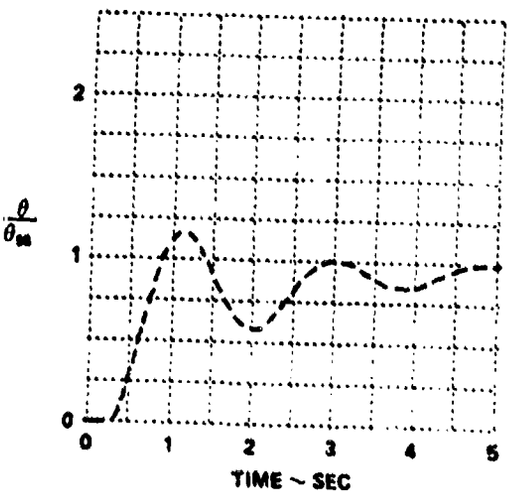
$1/T_{\theta_2}$	= 1.25	BW	= 3.0
n/α	= 18.5	Δ pc	= +20
V_T	= 480	K_L	= 0.59



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

1 B	CONFIGURATION ω_{sp} = 2.2 ζ_{sp} = 0.69 2.0/5.0/63

FLT./PILOT	1046/M	1074/W
PR/PIOR	3.5/1	3/1.5
$(F_s/n)/K_\theta$	6.0/6.05	6.5/6.50
K_p/K_{GH}	1.3/1.7	1.5/1.6
STICK FORCES	FORCES GO FROM HEAVY TO LIGHT. ABLE TO SELECT LIGHT STICK FORCES. NO NEED TO COMPROMISE BETWEEN MANEUVERING FORCES AND STEADINESS ON TARGET. AS STICK FORCES ARE MADE LIGHTER, THE FIRST PROBLEM WAS A CONCERN ABOUT OVER-STRESSING THE AIRPLANE. NO SECOND THOUGHTS.	NICE AND LIGHT - NO SECOND THOUGHTS.
PREDICTABILITY OF RESPONSE	GOOD IN PITCH ATTITUDE, POOR IN G. FORCES GO HEAVY TO LIGHT LEADING TO OVER-SHOOTING THE DESIRED G.	INITIAL RESPONSE SLOWER THAN DESIRABLE. FINAL RESPONSE - AIRPLANE DIGS IN AND TENDS TO OVERCONTROL - NOT PREDICTABLE. FAST PULSE TECHNIQUE USED WITH SUCCESS.
ATTITUDE CONTROL/ TRACKING CAPABILITY	REALLY GOOD, EXCELLENT. CAN PUT IT QUICKLY ON TARGET AND THEN IT IS STEADY AS A ROCK.	RELATIVELY GOOD. CAN STOP THE RESPONSE ON TARGET BUT DOESN'T MOVE AS FAST AS DESIRABLE.
NORMAL ACCELERATION CONTROL	A PROBLEM, TEND TO OVER-SHOOT.	OVERSHOOTS IN G, DIGS IN WHEN FLOWN AGGRESSIVELY - BETTER WITH SLOWER INPUTS
EFFECTS OF RANDOM DISTURBANCES	DIDN'T BRING UP ANY PROB-LEM.	NO EFFECT.
IFR PROBLEMS	NOTHING NEW.	NOTHING NEW. ON D.E. TRACK ING TASK THERE IS A TENDENCY TO OVERSHOOT THE NEEDLE.
GOOD FEATURES	ITS ABILITY ON TARGET - CAN ACQUIRE A TARGET EASILY AND VERY STEADY ON TARGET. GOOD RESPONSE - VERY COMFORTABLE. OUT-STANDING AIR-TO-GROUND AIRPLANE.	TRACKING CAPABILITY, IF NOT APPROACHED TOO AGGRES-SIVELY. GOOD TRIM. LACK OF RESPONSE TO DISTURBANCES.
OBJECTIONABLE FEATURES	INABILITY TO PULL G PRE CISELY. HEAVY INITIAL FORCES FOR SMALL INPUTS. TENDS TO DIG IN AND PERHAPS YOU COULD OVERSTRESS IT.	TENDENCY TO OVER G THE AIRPLANE IS A MINOR OBJECTION.

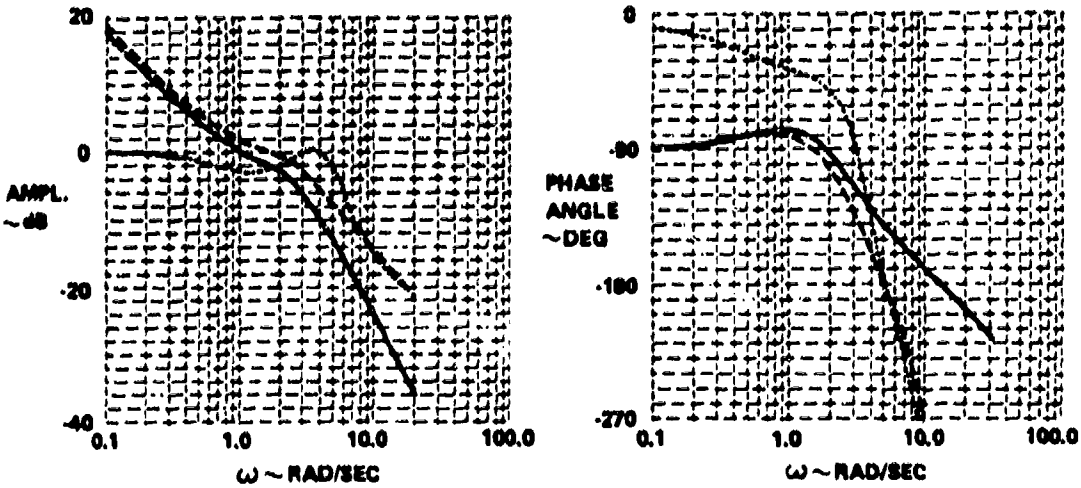
1 B

$1/T_{\theta_2}$	= 1.25	BW	= 3.0
n/α	= 18.5	Δ_{ps}	= +35
V_T	= 480	K_L	= 0.66

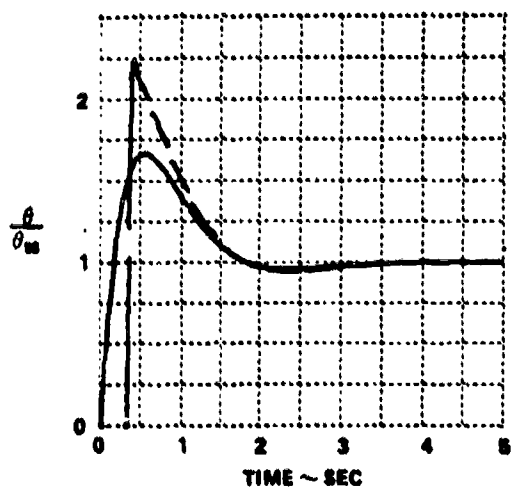
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

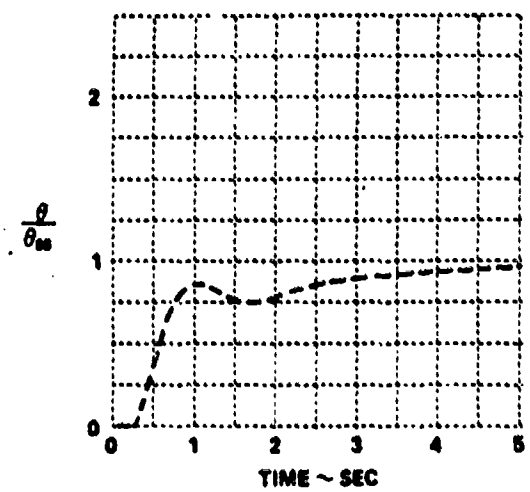
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

1C

CONFIGURATION
ω_{sp} = [illegible] ζ_{sp} = [illegible]
[illegible]

FLT/PILOT	[illegible]	[illegible]	[illegible]	[illegible]
PR/PIOR	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
STICK FORCES	GREAT VERY VERY PLEASANT	INITIAL FORCES ARE QUITE HEAVY RELATIVE TO THE STEADY FORCES PICKED GEARING PRIMARILY TO MAKE THE STEADY FORCES COMFORTABLE NO SECOND THOUGHTS ON GEARING SELECTION	COMFORTABLE NO SECOND THOUGHTS	O.K. NO SECOND THOUGHTS
PREDICTABILITY OF RESPONSE	GOOD EXCELLENT	NOT VERY GOOD LIGHTENING OF FORCES AS RESPONSE DEVELOPS IT DIGS IN AND OVERSHOOTS	SMALL OVERSHOOT IN PITCH ATTITUDE GOING FROM TARGET TO TARGET INITIAL RESPONSE IS GOOD FAIRLY PREDICTABLE	DIFFICULT TO ACQUIRE A TARGET THERE IS A TENDENCY TO OVERSHOOT AND BOBBLE INITIAL RESPONSE COULD BE FASTER BUT O.K. FINAL RESPONSE SOME DIFFICULTY IN PREDICTING BUT NOT A MAJOR PROBLEM
ATTITUDE CONTROL TRACKING CAPABILITY	GOOD	HAVE TO WORK TO ACQUIRE A TARGET TENDS TO OVERSHOOT SEVERAL TIMES BEFORE SETTLING DOWN ON TARGET QUITE STEADY ON TARGET HOWEVER	A PROBLEM HERE ALWAYS OVERSHOOT THE TARGET GOOD ONCE ON THE TARGET	THE PROBLEM WITH THE FINAL RESPONSE MAKES TRACKING DIFFICULT ADOPTED A PULSING TECHNIQUE TO MOVE THE AIRPLANE FROM POINT TO POINT
NORMAL ACCELERATION CONTROL	VERY GOOD	SOME PROBLEM HERE CAN OVERSHOOT G BECAUSE OF DIGGING IN TENDENCY	GOOD	GOOD SURPRISINGLY
EFFECTS OF RANDOM DISTURBANCES	NO PROBLEM HERE	SHOWS UP SOME TENDENCY TO PIO	NO PROBLEMS	DIDN'T SEEM TO HAVE MUCH EFFECT ON THIS CONFIGURATION
IFR PROBLEMS	O.K. TRACKING TASK PERFORMANCE WAS NOT AS GOOD AS EXPECTED BUT PERHAPS I'M GETTING LAZY	THE TRACKING TASKS SHOW UP SOME TENDENCY TO PIO	NOTHING NEW	NO SPECIAL PROBLEMS APPARENT
GOOD FEATURES	A GREAT AIRPLANE NICE LIGHT FORCES VERY SNAPPY COULD PULL ACCURATE G	STEADY ON TARGET STEADY FORCES ARE QUITE GOOD	GOOD MANEUVERABLE AIRPLANE COMFORTABLE FORCES TRACKS FAIRLY WELL WHEN ON TARGET CAN ACQUIRE TARGET	G CAPABILITY IS QUITE GOOD
OBJECTIONABLE FEATURES	DIDN'T TRIM UP VERY WELL BUT NOT A PROBLEM FOR THIS MISSION PRETTY FLAT GRADIENT HERE	DIFFICULT TO ACQUIRE A TARGET INITIAL FORCES ARE A LITTLE HEAVY LIGHTENING UP AS RESPONSE DEVELOPS TENDENCY TO OVERSHOOT G	SMALL OVERSHOOT WHEN ACQUIRING A TARGET SOME SMALL OSCILLATIONS IN G COULD BE STEADIER ON TARGET AND TRACKING THESE ARE MINOR FEATURES	TENDENCY TO OVERSHOOT AND BOBBLE ONCE OR TWICE WHEN ACQUIRING A TARGET

*RATINGS NOT USED IN DATA ANALYSIS SEE DISCUSSION AT THE BEGINNING OF THIS APPENDIX

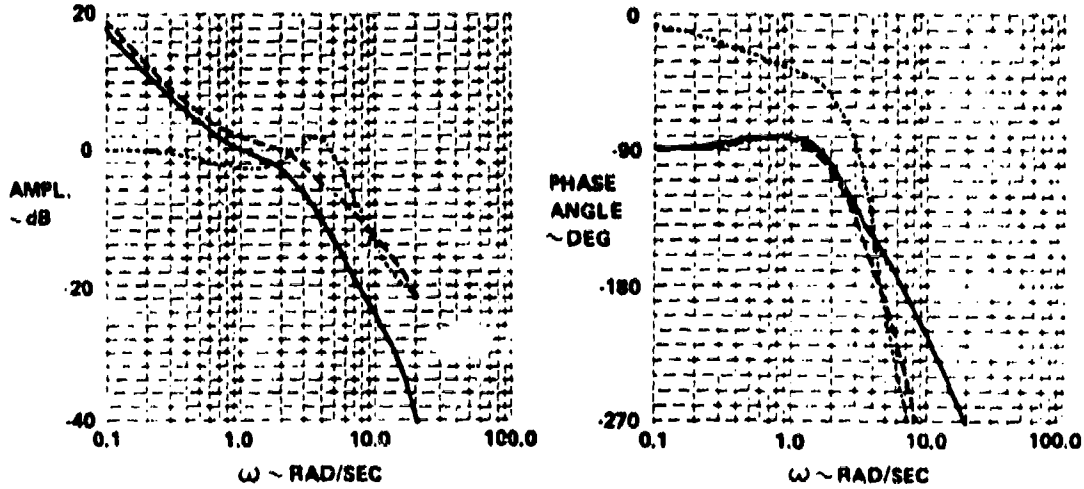
1C

$1/T_{\theta_2}$	= 1.25	BW	= 3.0
n/α	= 18.5	Δ_{ps}	= +4.2
V_T	= 480	K_L	= 0.79

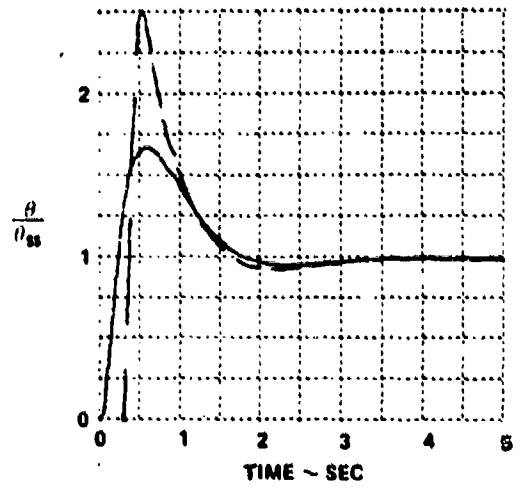
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

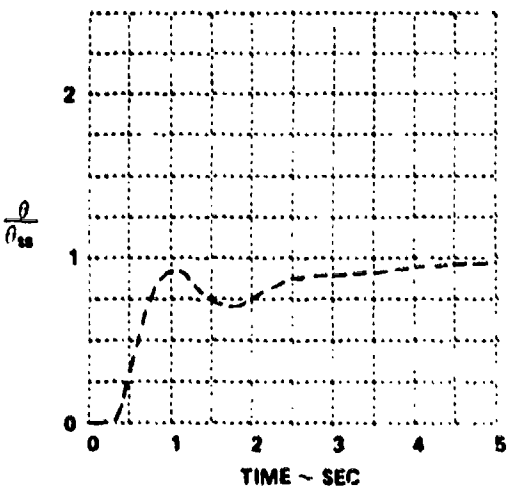
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

1 D	CONFIGURATION ω_{sp} = 2.2 ζ_{sp} = 0.66 n / α / 7½

PILOT/PILOT	1063/M	1067/M	1063/W	1067/W
PAPION	5/2.5	4.5/2	3/1	4/2
$(\Phi_p/\alpha/n_z)_\theta$	5.5/5.43	4.5/5.69	4.2/4.91	5.5/7.65
$\Phi_p/n_{z_{BW}}$	2.5/1.5	1 1/2.1	2.5/1.5	1.3/7.7
STICK FORCES	HEAVY INITIALLY LIGHTENING UP DRAMATICALLY. FELT VERY HEAVY IN RR TRACKING TASK WITH SMALL HIGH FREQUENCY INPUTS. FOR STEADY G, LIGHT, AT TIMES TOO LIGHT	QUITE LIGHT. NO SECOND THOUGHTS TO THE LIGHTNESS FACTOR INCREASING OF OVERSTRESSING. NOT PRECISION TRACKING.	NO COMPLAINTS.	QUITE ACCEPTABLE. REALLY NO SECOND THOUGHTS
PREDICTABILITY OF RESPONSE	FINAL RESPONSE POOR - ABLE TO ADAPT BUT EFFORT REQUIRED TO DO SO OR LEARN TO OVERDRIVE INITIALLY, THEN BLACKEN OFF CAN BE DONE.	NOT VERY GOOD. HEAVY INITIAL FORCES WHICH LIGHTEN UP CONSIDERABLY WHICH CAUSES A POOR G CAPABILITY. INABILITY TO CORRECTLY PREDICT WHAT THE FINAL G WILL BE CAUSING SOME TRACKING PROBLEMS.	QUITE GOOD. INITIAL RESPONSE BIT SLOWER THAN OPTIMUM, MUST OVERDRIVE IT TO GET SATISFACTORY INITIAL RESPONSE.	INITIAL RESPONSE NOT AS SNAPPY AS DESIRED FINAL RESPONSE CAN LEARN TO STOP IT WHERE YOU WANT TO OVERALL PREDICTABILITY IS PRETTY GOOD MUST LEARN TO OVERDRIVE AIRPLANE AND THEN TAKE OUT INPUT SLOWLY
ATTITUDE CONTROL/ TRACKING CAPABILITY	STEADY ON TARGET. SMALL OSCILLATION WHEN RAPID ATTITUDE CHANGES ATTEMPTED. NOT TOO BAD ON THE WHOLE	STEADY ON TARGET. FOR SMALL PITCH ATTITUDE CORRECTIONS HAD EXCELLENT BUT FOR LARGE AMPLITUDE MANEUVERS WITH SUBSTANTIAL G GET OVERSHOOTS OF TARGET.	GOOD.	PRETTY GOOD JUST GO AT A SLOWER RATE THAN DESIRED
NORMAL ACCELERATION CONTROL	NOT GOOD. TENDENCY TO "DIG IN" AND OVERSTRESS.	A PROBLEM TENDS TO DIG IN AND OVERSHOOT THE G. FORCES BIT QUITE A BIT LIGHTER IN MANEUVERING.	GOOD.	TENDENCY TO OVERCONTROL IN G IS A LITTLE BIT OF A PROBLEM
EFFECTS OF RANDOM DISTURBANCES	DON'T REALLY SHOW ANY THING.	ROUGH AIR SHOWED UP TENDENCY TO OVERSHOOT IN PITCH ATTITUDE.	VERY MINIMAL EFFECT ON THE AIRPLANE	MAGNITUDE OF RESPONSE TO DISTURBANCES IS LARGE AND DIFFICULT TO CONTROL WITH THE SLOW AIRPLANE RESPONSE TO CONTROL INPUTS.
IFR PROBLEMS	RR TRACKING TASK, FORCES FELT VERY HEAVY FOR SMALL INPUTS. DISCRETE ERROR OVERSHOOT AND WOBBLE BUT COULD DO WELL NO TENDENCY FOR PIO SURPRISING TO PILOT.	G. E. TRACKING TASK REALLY SHOWED OVERSHOOT TENDENCY	AS GOOD, IF NOT BETTER, IFR THAN VFR. MUST FORCE THE AIRPLANE A BIT TO DO THE G.E. TRACKING TASK.	NOTHING NEW IFR SLIGHT OVERSHOOT IN G. E. TRACKING TASK. RR TRACKING TASK DIFFICULT TO DO WITH SLOW AIRCRAFT RESPONSE.
GOOD FEATURES	GOOD ON TARGET; SMALL TENDENCY TO GOBBLE BUT OVERALL NOT BAD.	GOOD AIR-TO-GROUND CAPABILITY, STEADY ON TARGET, GOOD FOR SMALL ATTITUDE CHANGES. FORCES QUITE LIGHT AND COMFORTABLE	G CAPABILITY AND MANEUVERING CHARACTERISTICS ARE VERY GOOD. VERY SOLID ON TARGET.	PITCH ATTITUDE CONTROL AND TRACKING CAPABILITIES GOOD TRIM.
OBJECTIONABLE FEATURES	LACK OF ABILITY TO PULL G RAPIDLY AND PRECISELY; HEAVY INITIAL FORCES THEN LIGHT DIGS IN.	TEND TO OVERSHOOT FOR LARGE AMPLITUDE MANEUVERS. OSCILLATE IN G PARTICULARLY IFR. AIRPLANE DIGS IN INITIAL FORCES HEAVY. STEADY STATE LIGHT	MINOR: THE INITIAL RESPONSE IS NOT QUITE FAST ENOUGH; MUST OVERDRIVE IT AT TIMES.	SLOW RESPONSE TO CONTROL INPUTS. TENDENCY TO OVER CONTROL IN G.

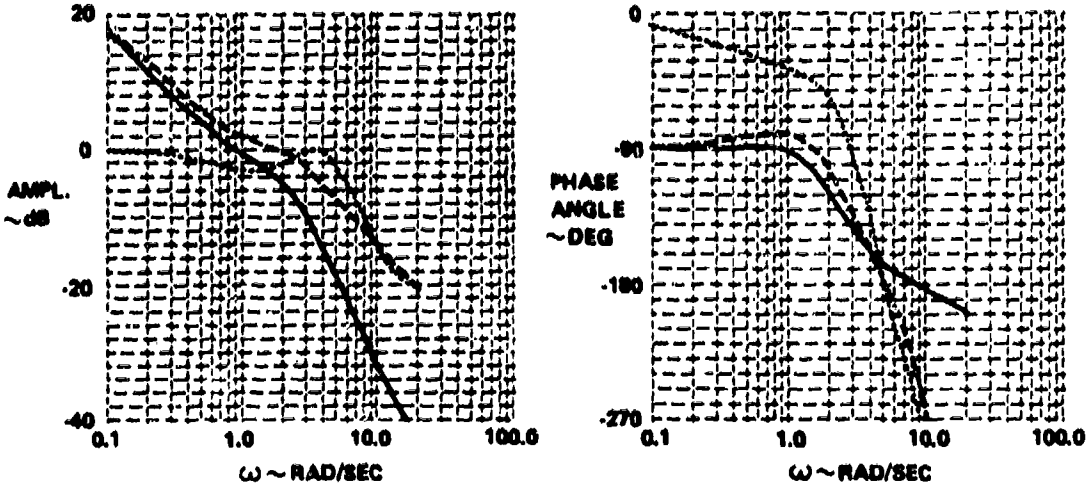
1D

$1/\tau_{\theta_2}$ = 1.25	BW = 3.0
n/α = 18.5	ϕ_{pc} = +60
V_T = 480	K_L = 0.85

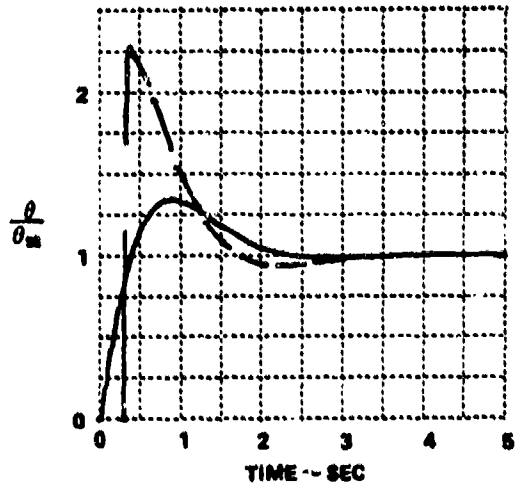
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

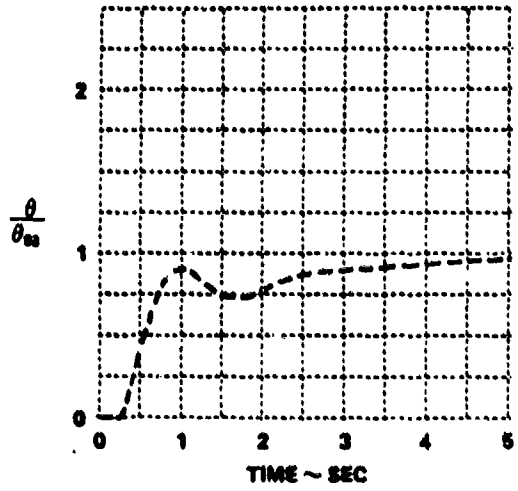
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

1 E	CONFIGURATION ω_{sp} = 2.2 ζ_{sp} = 0.60 - / 0 / 63

PLT./PILOT	103S/M
PR/PIOR	0/3.5
$(F_s/n)/K_\theta$	9.0/0.43
K_p/K_{BW}	1.7/5.9
STICK FORCES	ON THE HEAVY SIDE BUT A GOOD COMPROMISE ACHIEVED. DIFFICULT TO BE SURE OF EXTRAPOLATION TO 7 G. INITIAL FORCES HEAVY, TENDING TO LIGHTEN UP.
PREDICTABILITY OF RESPONSE	AIRPLANE TENDS TO DIG IN AND LIGHTENING FORCES MAKE IT DIFFICULT TO PRE DICT THE FINAL RESPONSE. HOWEVER, WAS ABLE TO ADAPT VERY WELL TO PREDICT FINAL RESPONSE.
ATTITUDE CONTROL/ TRACKING CAPABILITY	POOR, VERY POOR GOT USED TO IT AND DEVELOPED A TECHNIQUE TO GREATLY IM PROVE IT. BUT IT'S STILL A BAD AIRPLANE. PROBLEM IS A PIO TENDENCY IN TRACKING OR ATTITUDE CONTROL.
NORMAL ACCELERATION CONTROL	SURPRISINGLY GOOD.
EFFECTS OF RANDOM DISTURBANCES	NO PROBLEMS WHICH WAS SURPRISING CONSIDERING THE PIO TENDENCIES.
IFR PROBLEMS	REALLY ABLE TO DO QUITE A GOOD JOB, BETTER THAN VFR. DIDN'T SEE MUCH TENDENCY TO PIO IN D.E. TRACKING TASK. AGAIN THINK VFR TRACKING TASK IS MORE DEMANDING.
GOOD FEATURES	CAN PULL THE G I WANT FAIRLY WELL. FORCES LIGHTEN UP, ALLOWING REASONABLE STEADY STATE STICK FORCE PER G.
OBJECTIONABLE FEATURES	TENDENCY TO PIO WHEN ON TARGET, HEAVY INITIAL FORCES AND THEN A LIGHTEN-ING REQUIRES COMPENSATION.

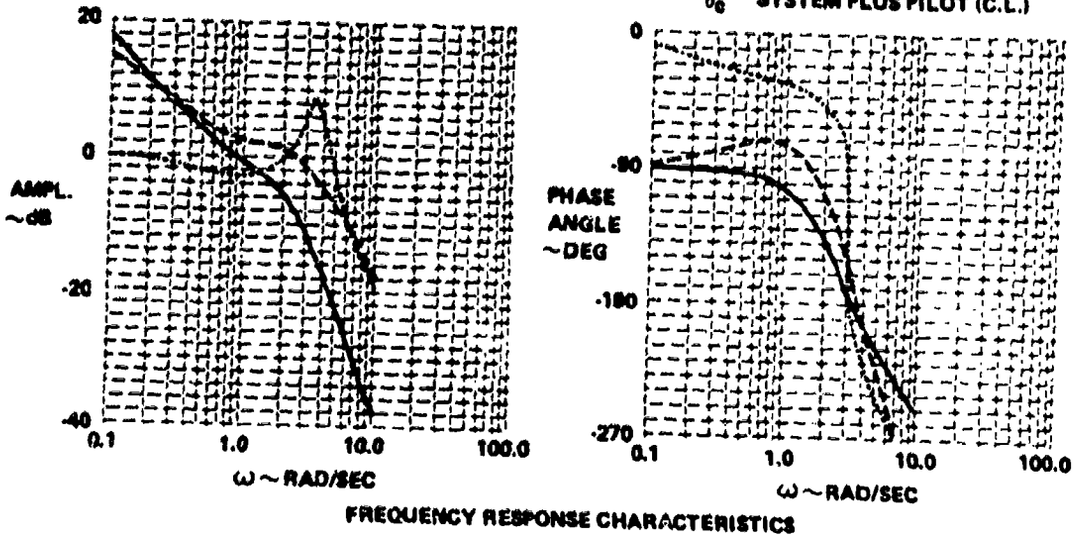
1 E

$1/T_{\theta_2}$ = 1.26	BW = 3.0
n/α = 18.8	$\Delta\mu_{sp}$ = +73
V_T = 480	K_L = 0.72

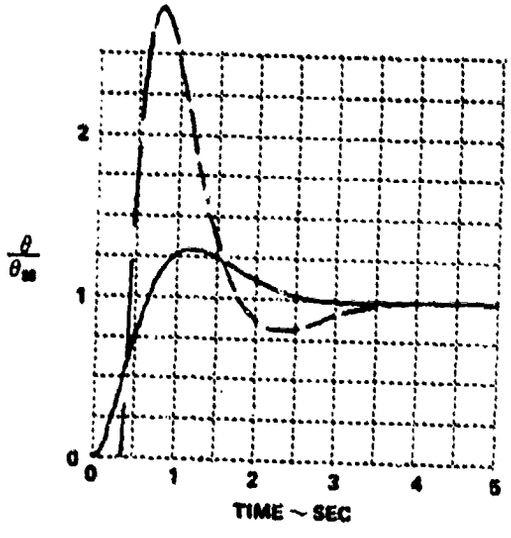
——— $\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

– – – $\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

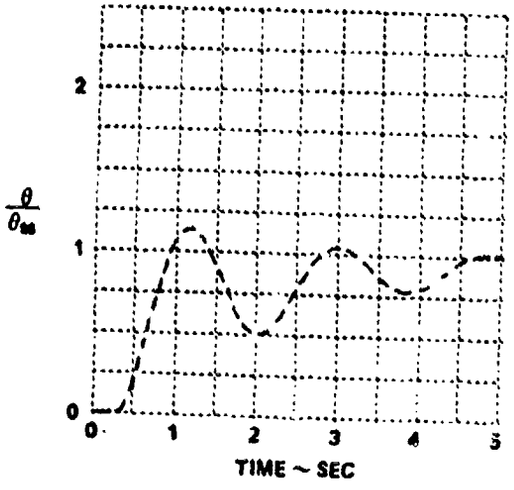
– – – – $\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO ΔF_s OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

1 F	CONFIGURATION ω_{sp} = 2.2 ζ_{sp} = 0.66 -/2/63

FLT./PILOT	1633/M	1634/W
PR/PIOR	0/4	0/4
$(P_s/n)/K_\theta$	14.4/0.27	6.6/0.06
n_p/K_{SW}	2.0/16.0	1.1/6.8
STICK FORCES	COMMENTS LOST	HEAVIER THAN DESIRED FOR A FIGHTER BUT NECESSARY TO PREVENT STRONG TENDENCY TO OVER G.
PREDICTABILITY OF RESPONSE	COMMENTS LOST	ALMOST IMPOSSIBLE. INITIAL RESPONSE IS QUITE DELAYED AND THEN THE AIRPLANE TAKES OFF AND OVERSHOOTS IN A LOW FREQUENCY BUT PERSISTENT MANNER.
ATTITUDE CONTROL/ TRACKING CAPABILITY	COMMENTS LOST	VERY, VERY POOR. DEFINITELY UNACCEPTABLE; VERY EASY TO GET 180° OUT OF PHASE AND GET A MEDIUM FREQUENCY PIO. COULD NOT KEEP AIRPLANE ON TARGET.
NORMAL ACCELERATION CONTROL	COMMENTS LOST	EXTREMELY POOR. COULD NOT LEARN HOW TO CHECK RESPONSE AND GET DESIRED G LEVEL.
EFFECTS OF RANDOM DISTURBANCES	COMMENTS LOST	NOT A REAL BIG EFFECT.
IFR PROBLEMS	COMMENTS LOST	MORE DIFFICULTY CONTROLLING ATTITUDES IFR.
GOOD FEATURES	COMMENTS LOST	SLOWNESS OF RESPONSE PREVENTS SERIOUS PROBLEMS WITH G OVERSHOOTS.
OBJECTIONABLE FEATURES	COMMENTS LOST	CANNOT PERFORM THE FIGHTER MISSION. DELAY BETWEEN CONTROL INPUT AND THE ATTITUDE CHANGE OF THE AIRPLANE. EASY TO GET INTO A PIO.

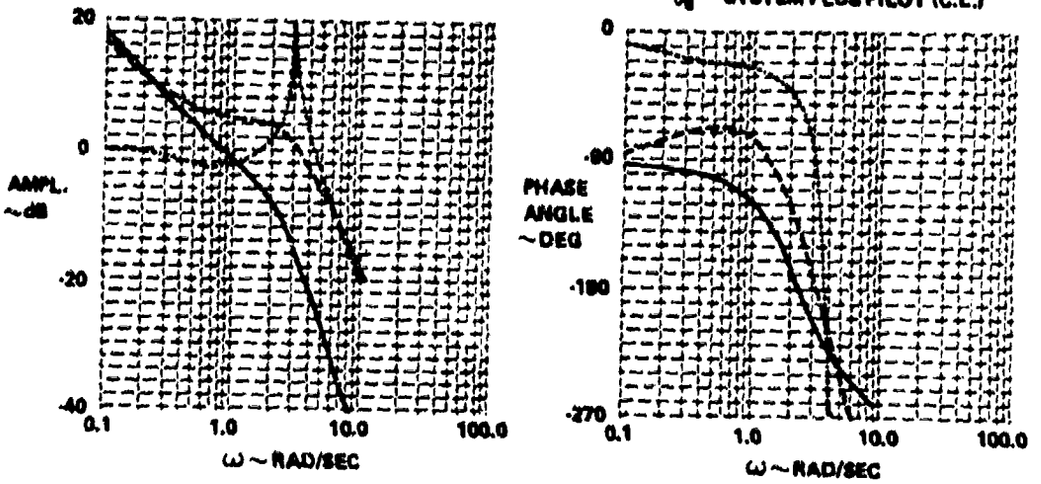
1 F

$1/T_{\theta_2}$ = 1.25	BW = 3.0
ω_{SP} = 19.5	ζ_{SP} = +60
V_T = 480	K_L = 0.71

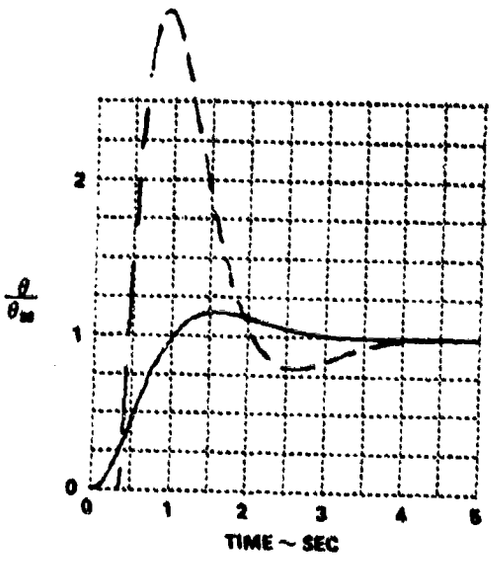
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

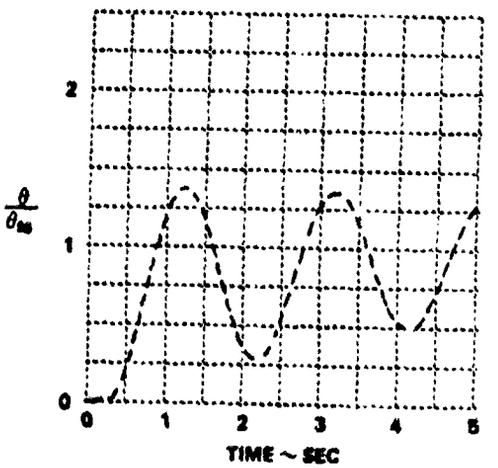
$\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

1 G	CONFIGURATION ω_{sp} = 2.2 ζ_{sp} = 0.66 - /0.6/63

FLT./PILOT	1030/M	1061/W
PR/PION	8.5/4.5	8.5/4
$(\Phi_v/n)/K_\theta$	6.0/0.66	4.6/0.83
K_p/K_{SW}	3.0/16.6	2.3/14.1
STICK FORCES	COMMENTS LOST	WOULD HAVE LIKED LIGHTER FORCES TO MAKE IT EASIER TO GET AIRPLANE MOVING INITIALLY, BUT THIS MADE IT EASIER TO OVERCONTROL DION'T REALLY LIKE THE FORCES SELECTED BUT THEY WERE A REASONABLE COMPROMISE.
PREDICTABILITY OF RESPONSE	COMMENTS LOST	VERY DIFFICULT TO PREDICT MARKED TENDENCY TO OVER CONTROL. HAVE TO USE LARGE INITIAL INPUT, AND THEN IMMEDIATELY TAKE IT OUT. USE PULSE-LIKE INPUTS.
ATTITUDE CONTROL/ TRACKING CAPABILITY	COMMENTS LOST	VERY POOR, PRACTICALLY NIL CAN NEVER GET AIRPLANE TO SETTLE DOWN DURING TIGHT TRACKING CANNOT TRACK
NORMAL ACCELERATION CONTROL	COMMENTS LOST	ALSO PRACTICALLY NIL.
EFFECTS OF RANDOM DISTURBANCES	COMMENTS LOST	MARKED EFFECTS TENDS TO CAUSE PIO'S IF YOU TRY TO NEGATE R.N. DISTURBANCES
IFR PROBLEMS	COMMENTS LOST	NO NEW PROBLEMS. SLIGHT TENDENCY TOWARD PIO ON R.N. TRACKING TASK.
GOOD FEATURES	COMMENTS LOST	CAN'T THINK OF ANY.
OBJECTIONABLE FEATURES	COMMENTS LOST	BIG INITIAL DELAY IN RESPONSE AND POOR PREDICTABILITY. PIO TENDENCIES DURING TIGHT TRACKING AND IN R.N. DISTURBANCES

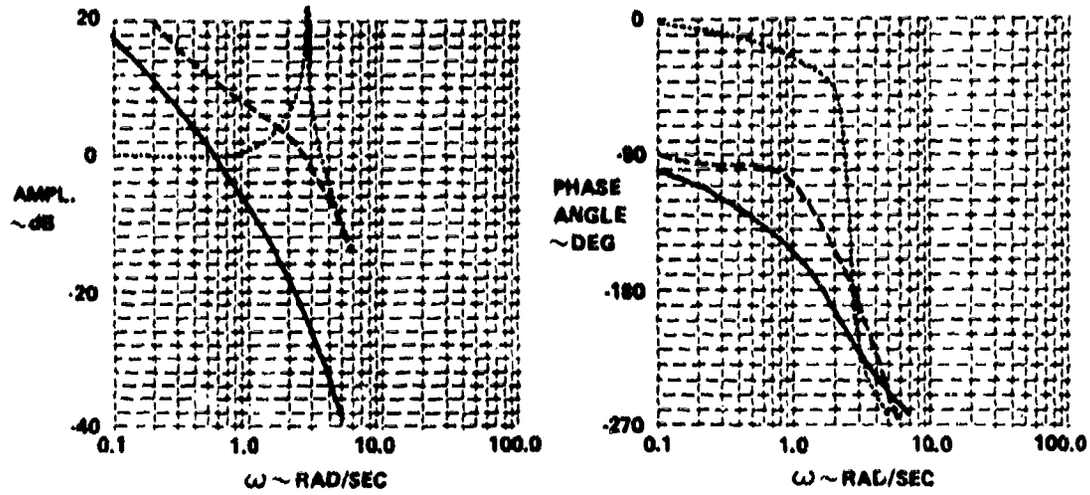
1 G

$1/T_{\theta_2}$	= 1.25	BW	= 2.7
n/α	= 18.5	$\angle$ pc	= +80
V_T	= 480	K_L	= 1.94

$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



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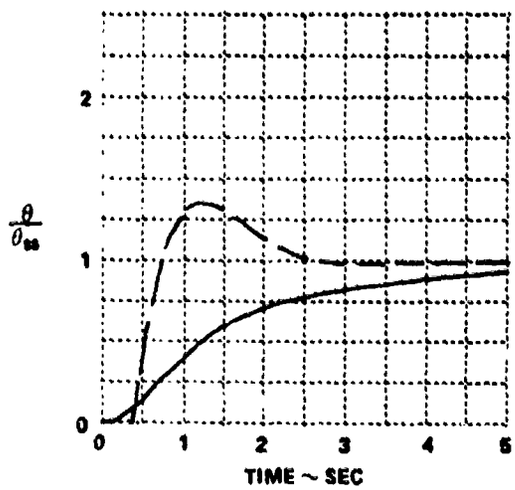
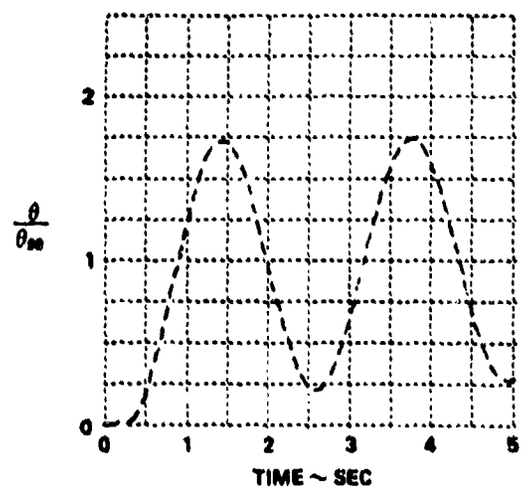


OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



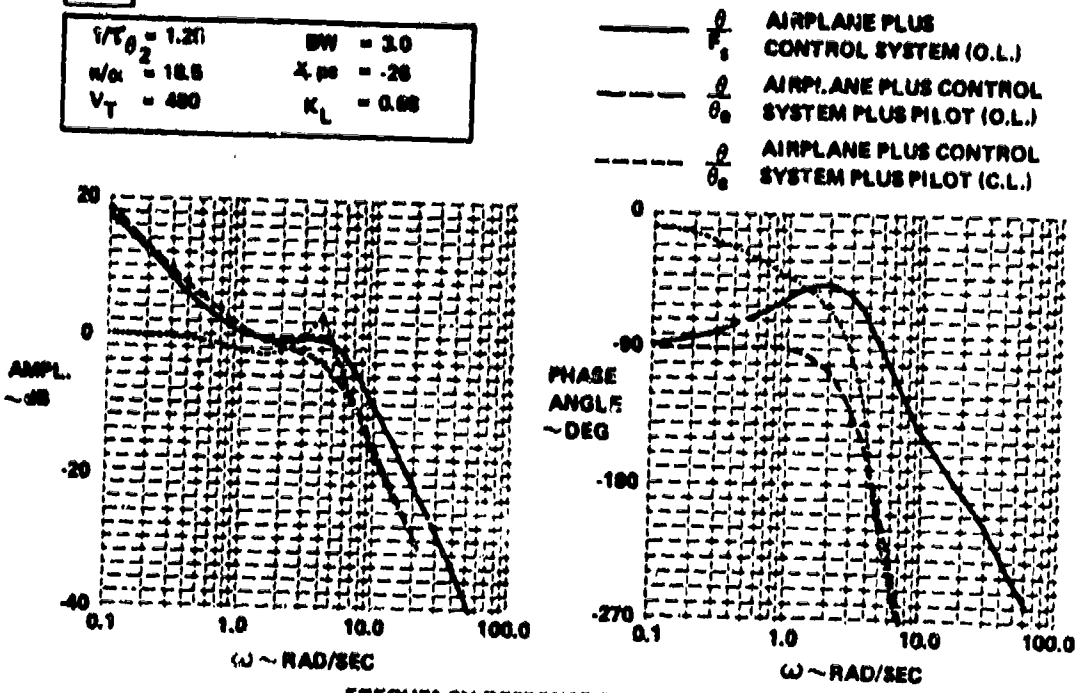
CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

2 A	CONFIGURATION ω_{sp} = 4.0 ζ_{sp} = 0.70 2/6/63

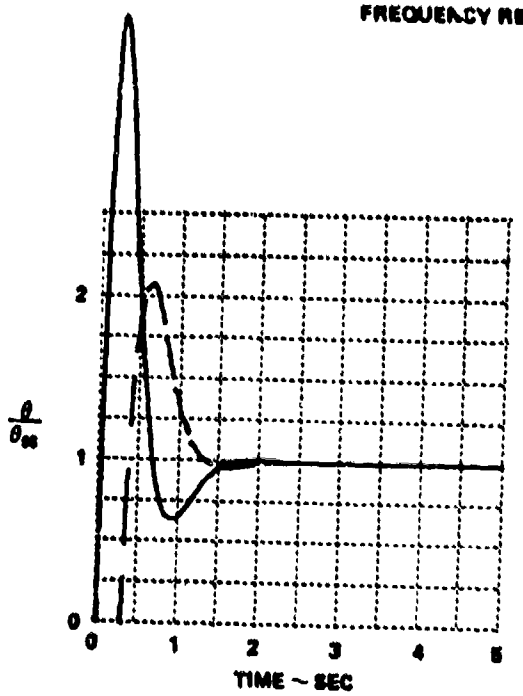
PLT./PILOT	1948/M	1951/W
PR/PIOR	4.5/2	4/2
$(\Phi_\phi/n)/K_\theta$	5.9/0.63	5.1/0.75
K_p/K_{BW}	1.4/0.87	1.2/0.76
STICK FORCES	ON THE HEAVY SIDE FOR STEADIER TRACKING - NO SECOND THOUGHTS. FORCES TEND TO GO FROM LIGHT TO HEAVY.	HAPPY WITH GEARING SELECTION.
PREDICTABILITY OF RESPONSE	NOT TOO GOOD. CONSISTENTLY OVERSHOT THE TARGET. FLY IT SMOOTHLY.	RESPONSE TAKES OFF QUITE RAPIDLY AT FIRST, BUT NOT TOO RAPIDLY. SEEMS QUITE PREDICTABLE. HAVE TO MAKE CONSCIOUS EFFORT TO KEEP INPUTS SMOOTH.
ATTITUDE CONTROL/ TRACKING CAPABILITY	CONSISTENTLY OVERSHOOT THE TARGET. STEADY ON TARGET.	QUITE GOOD. SLIGHT TENDENCY TO OVERSHOOT; BUT BY SMOOTHING INPUTS SLIGHTLY, ATTITUDE CONTROL IS QUITE ACCURATE
NORMAL ACCELERATION CONTROL	TEND TO OVERSHOOT MY G BOTH VFR AND IFR. FELT AS THOUGH IT WOULD OSCILLATE IN PITCH, BUCK, WHILE TRACKING UNDER G LOADS.	ESPECIALLY GOOD.
EFFECTS OF RANDOM DISTURBANCES	NO PROBLEMS.	VERY LITTLE EFFECT.
IFR PROBLEMS	NO PROBLEMS WITH TRACKING TASKS EXCEPT THE OVERSHOOT WHICH ALSO SHOWED UP VFR.	NO NEW PROBLEMS. TRACKING TASKS AGAIN SHOWED UP OVERSHOOTING TENDENCY WHEN FLOWN AGGRESSIVELY.
GOOD FEATURES	STEADY ON TARGET, CAN PULL G IN VICINITY OF DESIRED LEVEL QUICKLY.	GOOD MANEUVERING CAPABILITY. TRACKING CAPABILITY IS NOT OUTSTANDING, BUT IS GOOD.
OBJECTIONABLE FEATURES	FORCES GET HEAVY MANEUVERING, OVERSHOOT THE TARGET. G CONTROL IS NOT PRECISE.	MINOR

2 A

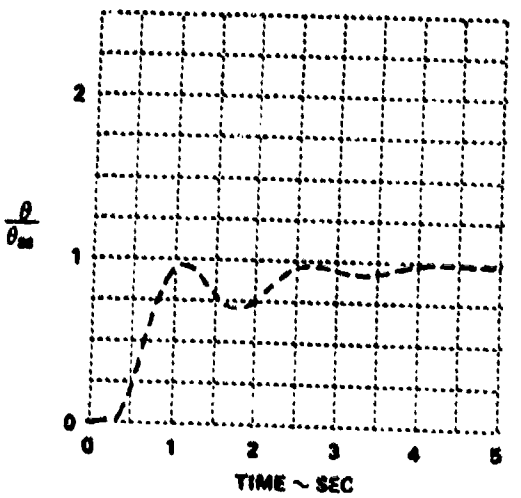
$1/T_{\theta_2}$	= 1.251	BW	= 3.0
n/α	= 18.5	ζ_{ps}	= .26
V_T	= 450	K_L	= 0.68



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

28	CONFIGURATION ω_{sp} = 4.9 ζ_{sp} = 0.70 7/5/16

FLT/PILOT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
PR/PIOR	2.5/1.5	6/2.5	6/3	4/1.5	5/2.5
$F_s/n/F_{s_{ss}}$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
δ_p/δ_{ss}	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
STICK FORCES	ON THE HEAVY SIDE BUT WOULDN'T CHANGE IT. FORCES HEAVY UP AS YOU GO INTO A MANEUVER	PRETTY GOOD. TRIED HEAVIER FORCES TO TRY TO HELP TRACKING CAPABILITY. DIDN'T HELP MUCH. SO GEARING WAS SELECTED TO MAKE STEADY FORCES COMFORTABLE. STEADY FORCES ARE COMPATIBLE WITH INITIAL FORCES. NO SECOND THOUGHTS ON GEARING	A COMPROMISE BETWEEN VERY HEAVY MANEUVERING FORCES AND HAVING JUST TOO RESPONSIVE AN AIRPLANE. NO SECOND THOUGHTS	OK	NO SECOND THOUGHTS ON GEARING SELECTION
PREDICTABILITY OF RESPONSE	SEEMS TOO RESPONSIVE. EXTREMELY RESPONSIVE. PREDICTABLE	NOT VERY GOOD. PRETTY ERRATIC AIRPLANE. FLY IT SMOOTHLY	NOT VERY GOOD. INITIAL RESPONSE TOO FAST. TEND TO OVERSHOOT THE TARGET QUITE BADLY. FORCES GO FROM LIGHT TO HEAVY. FLY AS SMOOTHLY AS THE SITUATION WILL PERMIT	SOME DIFFICULTY HERE. INITIAL RESPONSE QUITE SNAPPY BUT FINAL RESPONSE TENDS TO OVERSHOOT VERY QUICKLY	A LITTLE STRANGE. VERY SLIGHT INITIAL HESITATION, THEN TAKES OFF IN A NICE FIGHTER LIKE MANNER. SO THE INITIAL RESPONSE SEEMS O.K. BUT THE FINAL RESPONSE IS A LITTLE DIFFICULT TO PREDICT. SOME TROUBLE IN STOPPING THE AIRPLANE RIGHT WHERE YOU WANT IT
ATTITUDE CONTROL/ TRACKING CAPABILITY	QUITE GOOD. VERY RESPONSIVE, YET PRECISE	REAL PROBLEM. POOR. OVERSHOOTS THE TARGET SEVERAL TIMES IN TRYING TO SETTLE DOWN ON TARGET. PRETTY STEADY ON TARGET, THOUGH	HEART OF PROBLEM IS ACQUIRING A TARGET. TEND TO OVERSHOOT AND THEN BOBBLE ABOUT THE TARGET ONCE ON TARGET. NOT VERY GOOD FOR TRACKING. SEEMS TO WANDER OFF THE TARGET	GOOD BUT SLIGHT TENDENCY TO OVERSHOOT IS A PROBLEM. NOT AS PRECISE AS DESIRED	ONLY FAIR. NOT A PIO, BUT YOU GET OUT OF PHASE WITH THE AIRPLANE, SO THAT YOU SORT OF FIND YOURSELF SEARCHING AROUND FOR THE TARGET
NORMAL ACCELERATION CONTROL	CAN REALLY NAIL THIS THING DOWN ON A TARGET OR A G AT WILL	POOR, BUT NOT NEARLY AS BAD AS ATTITUDE CONTROL. OVERSHOOTS MAYBE ONCE WHEN RAPIDLY ACQUIRING G	NOT AS BAD AS PITCH ATTITUDE. DO OVERSHOOT G AND BOBBLE AROUND DESIRED VALUE ABOUT 1/2 INCREMENTAL G	GOOD	QUITE GOOD FOR NORMAL MANEUVERING. FAIR FOR PULLING LARGE G VALUES PRECISELY. TEND TO UNDERSHOOT
EFFECTS OF RANDOM DISTURBANCES	NOTHING CAME TO LIGHT THERE	SHOWS UP A PIO TENDENCY OF THE AIRPLANE. NOT FULL BLOWN P.I.O. BUT LOTS OF OSCILLATIONS AND WEIRD MOTIONS	SHOWED UP A PIO TENDENCY THAT WAS NOT APPARENT BEFORE	EFFECTS NOTICEABLE AND WITH THE SNAPPY RESPONSE THERE WAS A TENDENCY TO OVERCONTROL	NO SIGNIFICANT EFFECT. BARELY NOTICEABLE
IFR PROBLEMS	NO PROBLEMS	TRACKING TASKS ALSO SHOW UP OSCILLATORY TENDENCIES	OVERSHOOT IN O.E. TRACKING TASK. VERY OSCILLATORY IN PR TAT.. SUSPECT POTENTIAL PROBLEMS IFR	NOTHING NEW. O.E. TRACKING TASK SHOWED UP OVERSHOOT TENDENCIES ON TRACKING TASK. NO PROBLEMS	NO NEW PROBLEMS. GOOD IFR AIRPLANE. SOME TENDENCY TO OVERCONTROL ON O.E. TRACKING
GOOD FEATURES	CAN WEAR IT LIKE A GLOVE. VERY QUICK FIGHTER LIKE AIRPLANE	FORCES ARE COMFORTABLE. NORMAL ACCELERATION CONTROL IS PRETTY GOOD FOR VFR MANEUVERING	MANEUVERING CAPABILITY IN SPITE OF OVERSHOOTING THE DESIRED G	C CAPABILITIES. LIGHT STICK FORCES. GOOD MANEUVERABILITY	OVERALL MANEUVERABILITY IS GOOD
OBJECTIONABLE FEATURES	PERHAPS TOO RESPONSIVE	QUITE A PROBLEM IN ACQUIRING A TARGET. OSCILLATE IN G QUITE A BIT IFR	TOO RESPONSIVE FOR SMALL INPUTS. OVERSHOOT THE TARGET AND BOBBLE BACK AND FORTH. NOT STEADY ON TARGET. FORCES ARE QUITE HEAVY AS A RESULT OF COMPROMISE IN F/n SELECTION	FOR LARGE ATTITUDE CHANGES GET AN OVERSHOOT WITH A COUPLE OF BOBBLES	DIFFICULT TO PREDICT ATTITUDE CHANGES. FOULS UP TRACKING SOMEWHAT

*RATINGS NOT USED IN DATA ANALYSIS. SEE DISCUSSION AT THE BEGINNING OF THIS APPENDIX

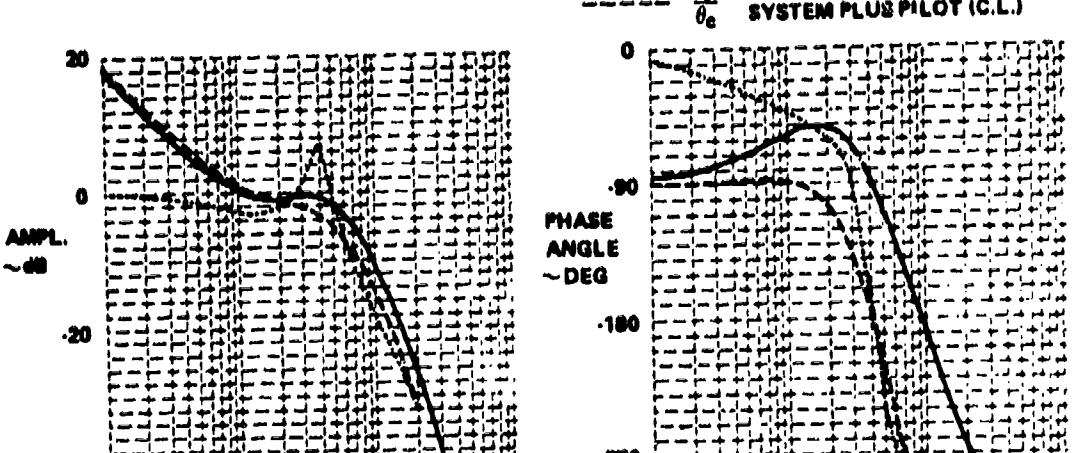
2 B

$1/T_{\theta_2}$ = 1.25	BW = 3.0
n/α = 18.5	Δ ps = -.20
V_T = 180	γ_L = 0.84

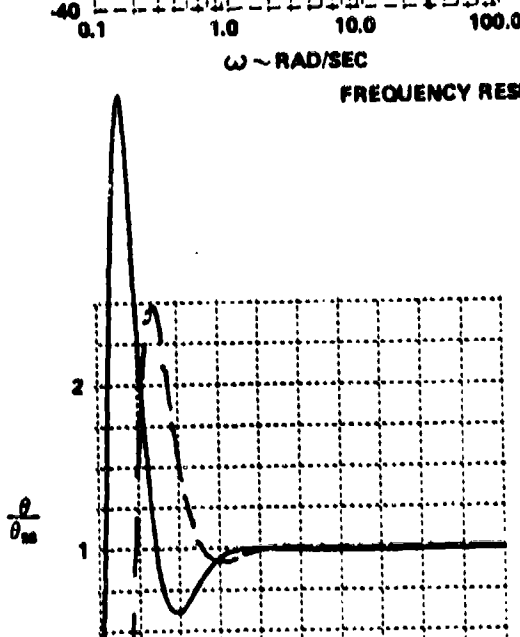
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

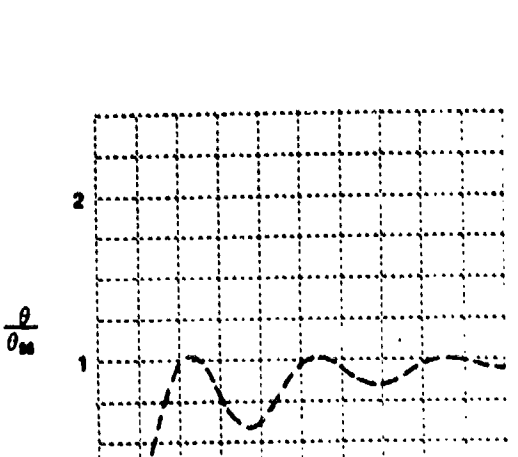
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

2C	CONFIGURATION ω_{sp} = 4.0 ζ_{sp} = 0.70 5/12/83

FLT./PILOT	1064/M
PR/PIOR	3./1.5
$(F_e/n)/K_\theta$	4.6/6.53
$\wedge_\theta/K_{BW}$	1.1/0.87
STICK FORCES	ABLE TO SELECT RELATIVELY LIGHT STICK FORCES. SECOND THOUGHTS - AFTER SOME DEBATE, THINKING THAT FORCES SHOULD HAVE BEEN HEAVIER. NONE.
PREDICTABILITY OF RESPONSE	GOOD, INITIAL FORCES AND MOTIONS COMMENSURATE WITH THE STEADY STATE.
ATTITUDE CONTROL/ TRACKING CAPABILITY	GOOD - COULD GET TO THE TARGET FAST AND, AFTER ONE OR TWO SMALL OVERSHOOTS, SETTLE DOWN NICELY. STEADY ON TARGET.
NORMAL ACCELERATION CONTROL	VERY QUICK WITH A SLIGHT TENDENCY TO BUCK.
EFFECTS OF RANDOM DISTURBANCES	NOTHING NEW.
IFR PROBLEMS	NOTHING NEW.
GOOD FEATURES	VERY RESPONSIVE, FIGHTER-LIKE AIRPLANE. COMFORTABLE FORCES, RELATIVELY LOW F/n, PREDICTABLE.
OBJECTIONABLE FEATURES	MINOR - SLIGHT TENDENCY TO OSCILLATE IN PITCH WHILE PULLING G WHICH DEGRADES TRACKING CAPABILITIES.

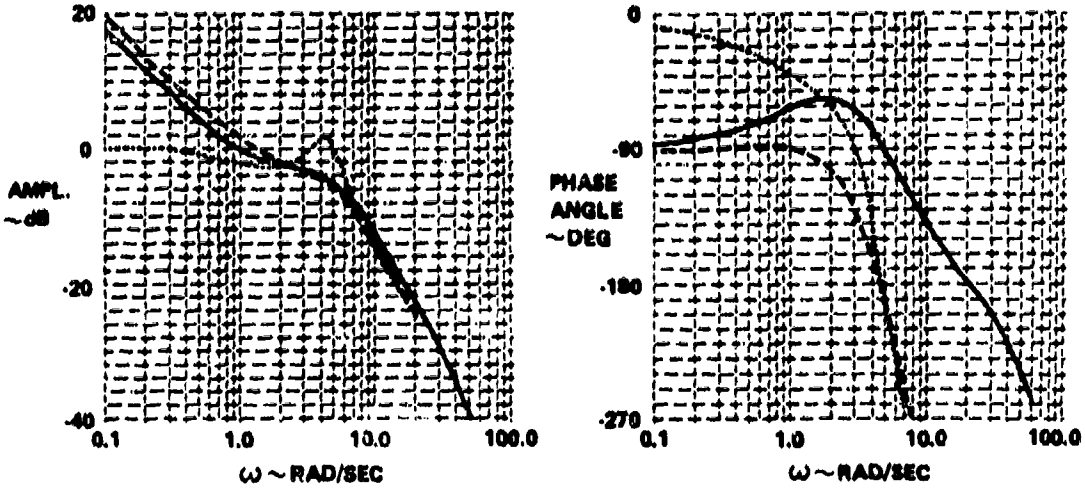
2 C

$1/\tau_{\theta_2}$	= 1.25	BW	= 3.0
n/α	= 16.5	ζ_{ps}	= .15
V_T	= 480	K_L	= 0.94

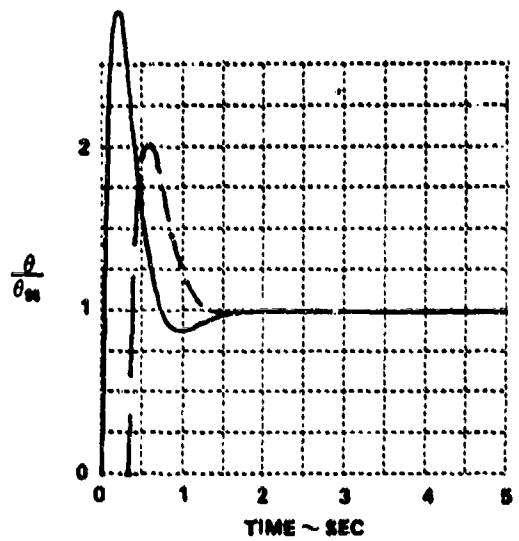
——— $\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

— — — $\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

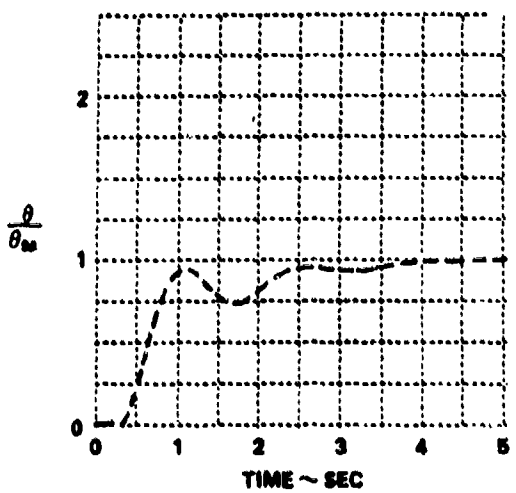
– – – – $\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

2D	CONFIGURATION ω_{sp} = 4.9 ζ_{sp} = 0.70 -/-/76

FLT./PILOT	1021/N	1045/M	1031/W
PR/PIOR	3/2	2.5/1	2.5/1
$(F_s/n)/K_G$	0.9/0.35	3.7/1.05	5.9/0.65
$K_{\dot{\gamma}}/K_{SW}$	2.4/2.2	0.90/0.83	1.4/1.3
STICK FORCES		VERY COMFORTABLE, A COMPROMISE BETWEEN TRACKING PRECISION AND MANEUVERING FORCES BUT NO SECOND THOUGHTS.	GOOD, PERHAPS COULD BE LIGHTER WITHOUT ANY PROBLEM.
PREDICTABILITY OF RESPONSE	INITIAL RESPONSE SOMEWHAT ABRUPT INITIAL RESPONSE IS GOOD INDICATION OF FINAL RESPONSE	GOOD FINAL AND INITIAL FORCES WERE COMPATIBLE	QUITE GOOD BOTH INITIAL AND FINAL RESPONSE
ATTITUDE CONTROL TRACKING CAPABILITY	GOOD, BUT SMALL OSCILLATIONS ON TARGET.	GOOD. TENDENCY TO OVER SHOOT TARGET AT LEAST ONCE.	GOOD.
NORMAL ACCELERATION CONTROL	GOOD, BUT SMALL OSCILLATIONS AROUND STEADY-STATE.	GOOD. COULD QUITE QUICKLY AND ACCURATELY PULL THE DESIRED G LEVEL.	GOOD.
EFFECTS OF RANDOM DISTURBANCES	DIDN'T SEEM TO SHOW UP UNUSUAL PROBLEMS	NO PROBLEM	DON'T SHOW MUCH
IFR PROBLEMS	NO OSCILLATIONS IFR BECAUSE FLYING MORE SMOOTHLY.	NOTHING NEW	NOTHING NEW IFR DISCRETE ERROR TRACKING TASK SLIGHT TENDENCY TO OVER SHOOT AND OSCILLATE JUST A TINY BIT, BUT NOT A PROBLEM
GOOD FEATURES	GOOD MANEUVERABILITY. GOOD ATTITUDE AND G CONTROL.	NICE AIRPLANE, COMFORTABLE FORCES, GOOD MANEUVERABILITY CHARACTERISTICS.	TRACKING CAPABILITY. LIGHT STICK FORCES AND MANEUVERABILITY GOOD CONTROL HARMONY
OBJECTIONABLE FEATURES	SMALL OSCILLATIONS ON TARGET.	COULD BE STEADIER ON TARGET. THIS IS MINOR OBJECTION.	NOTHING MAJOR. CAN FEEL A SMALL BUMP INITIALLY BUT DOESN'T DETRACT FROM ANYTHING

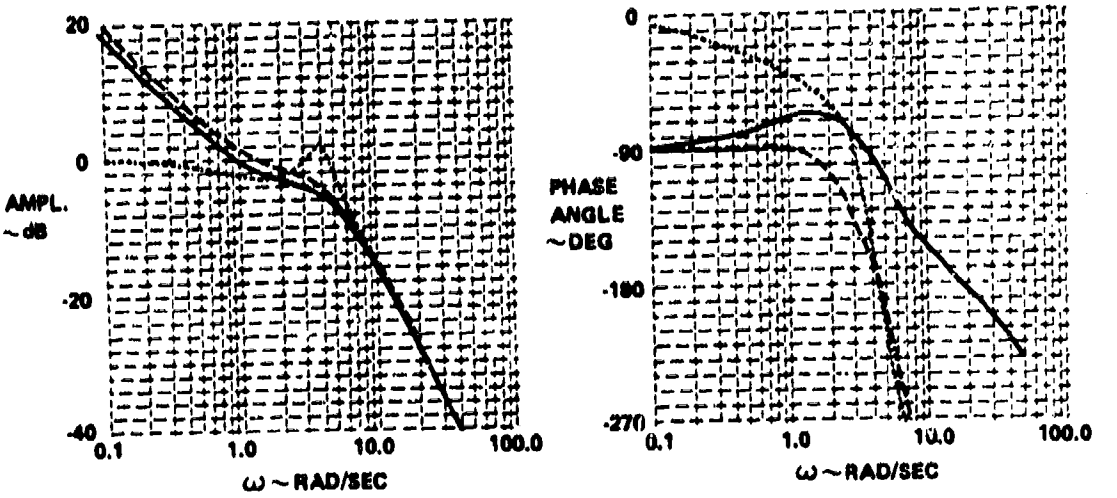
2 D

$1/\tau_{\theta_2}$	= 1.25	BW	= 3.0
n/α	= 18.5	ζ_{ps}	= .5
V_T	= 480	K_L	= 0.94

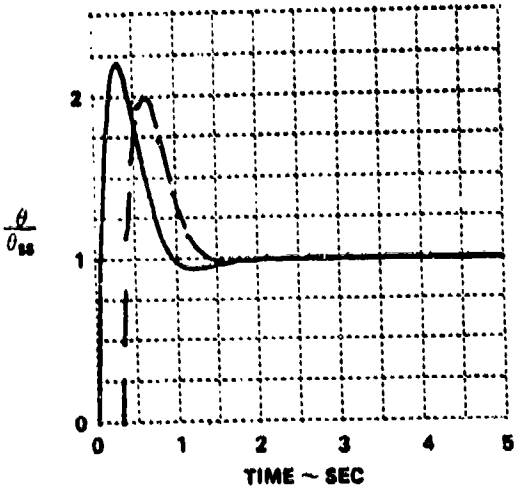
——— $\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

– – – $\frac{\theta}{\vartheta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

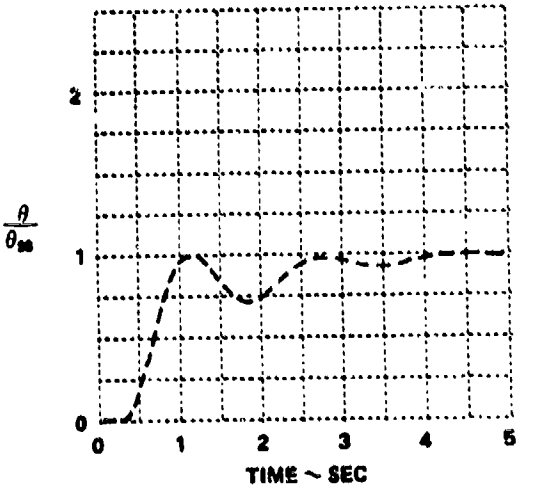
– – – – $\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

2 E	CONFIGURATION ω_{sp} = 4.0 ζ_{sp} = 0.70 – /12/63

FLT./PILOT	1045/M
PR/PIOR	4/1
$(F_s/n)/K_\theta$	3.8/1.09
K_p/K_{pm}	0.86/0.87
STICK FORCES	QUITE COMFORTABLE. SELECTED ON HEAVY SIDE TO REDUCE OVERSHOOT ON TARGET.
PREDICTABILITY OF RESPONSE	NOT TOO BAD. INITIAL AND STEADY FORCES COMPATIBLE.
ATTITUDE CONTROL/ TRACKING CAPABILITY	A PROBLEM, NOT SERIOUS THOUGH. CONTINUALLY OVERSHOOT THE TARGET. ONCE ON TARGET STEADY.
NORMAL ACCELERATION CONTROL	NOT TOO PRECISE. COULD PULL G QUICKLY BUT THERE WAS A TENDENCY TO OVER-SHOOT THE G.
EFFECTS OF RANDOM DISTURBANCES	DIDN'T CREATE A PROBLEM.
IFR PROBLEMS	NORMAL ACCELERATION PROBLEM SHOWED UP MAINLY IFR. CAN PULL G WITHOUT OSCILLATING LOOKING OUTSIDE - NOT SO ON INSTRUMENTS.
GOOD FEATURES	NICE, MANEUVERABLE, FORCES ARE O.K., CAN PULL G QUITE PRECISELY WITH IT VISUALLY. STEADY ON TARGET AND CAN GET THERE RELATIVELY QUICKLY.
OBJECTIONABLE FEATURES	NOT SERIOUS. TEND TO OVER-SHOOT THE TARGET - MUST COMPENSATE TO GET IT ON TARGET. OVERSHOOT IN G ON INSTRUMENTS.

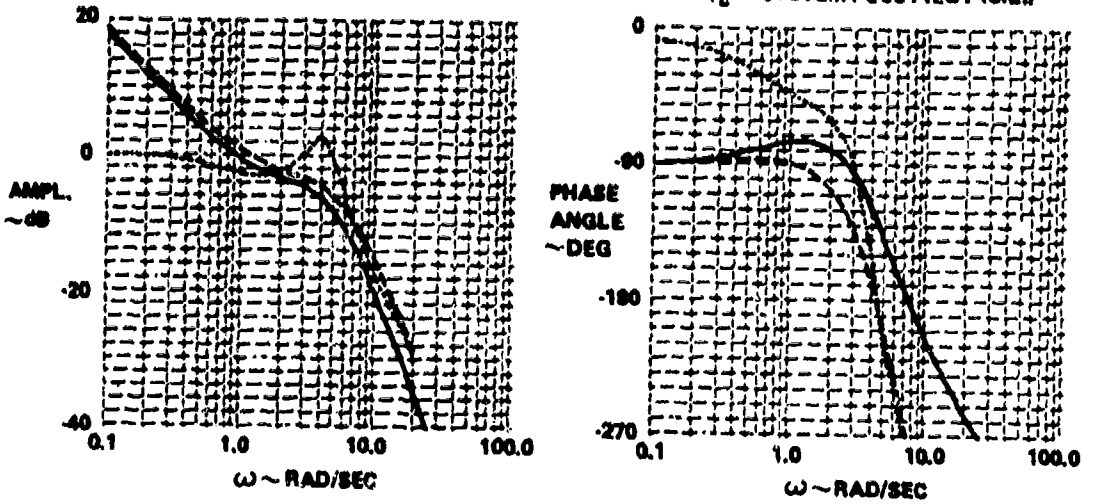
2 E

$1/\tau_{\theta_2}$	= 1.25	BW	= 3.0
n/α	= 18.5	$\angle_{pm}$	= +14
V_T	= 460	K_L	= 0.86

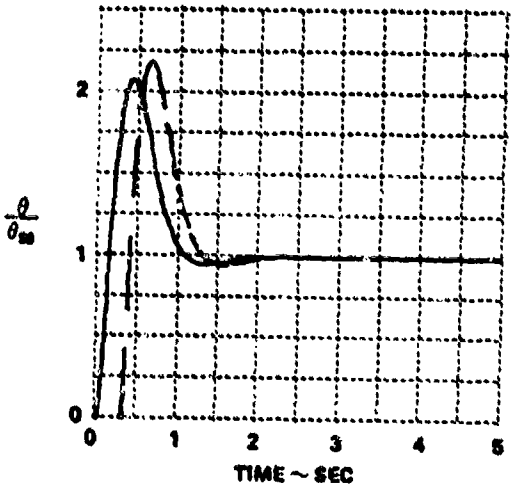
——— $\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

— — — $\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

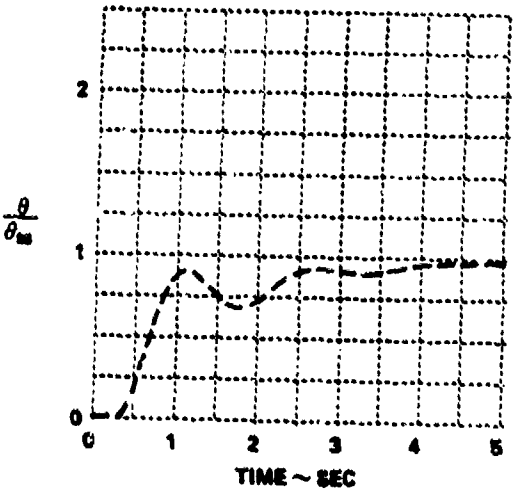
— — — $\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

2 F	CONFIGURATION ω_{sp} = 4.0 ζ_{sp} = 0.70 - /5/63

FLT./PILOT	1036/M
PR/PIOR	3/1
$(F_s/n)/K_\theta$	5.5/0.70
K_p/K_{BW}	1.3/1.5
STICK FORCES	GOOD; NO SECOND THOUGHTS.
PREDICTABILITY OF RESPONSE	GOOD.
ATTITUDE CONTROL/ TRACKING CAPABILITY	GOOD. SLIGHT TENDENCY TO OSCILLATE ON TARGET.
NORMAL ACCELERATION CONTROL	GOOD. SLIGHT OSCILLATIONS BUT NOT BAD AT ALL.
EFFECTS OF RANDOM DISTURBANCES	DIDN'T CAUSE A PROBLEM.
IFR PROBLEMS	NOTHING NEW.
GOOD FEATURES	IT'S A NICE FIGHTER TYPE AIRPLANE. NICE SNAPPY RESPONSES; GOOD CONTROL OF G.
OBJECTIONABLE FEATURES	TENDENCY TO BOBBLE ON TARGET A LITTLE BIT. CERTAINLY NOT SERIOUS.

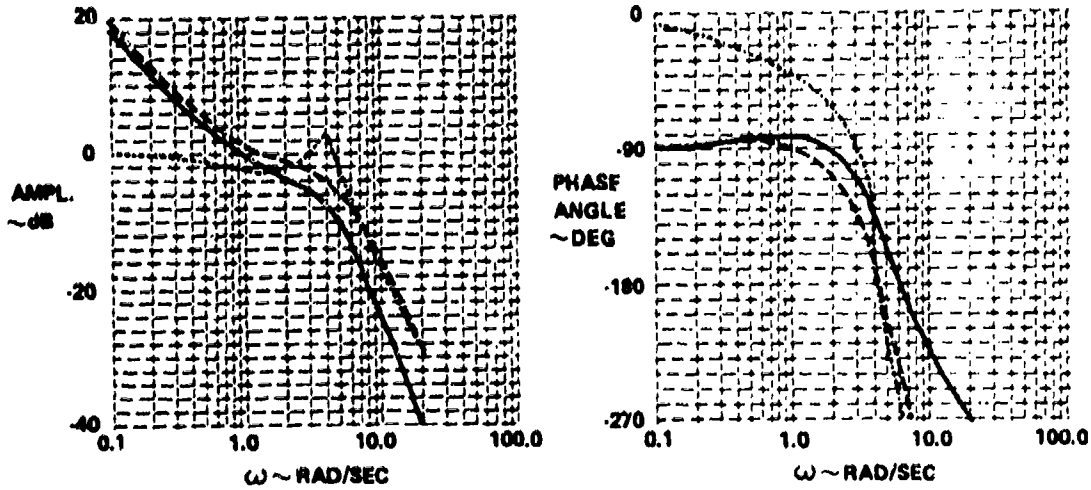
2 F

$1/T_{\theta_2}$ = 1.25	BW = 3.0
n/α = 18.5	$\angle\mu$ = +29
V_T = 480	K_L = 0.91

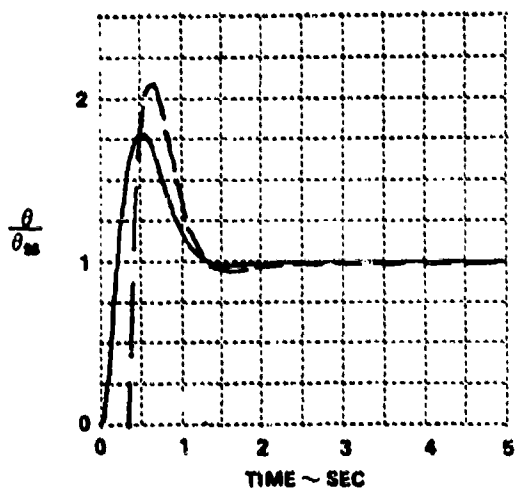
——— $\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

– – – $\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

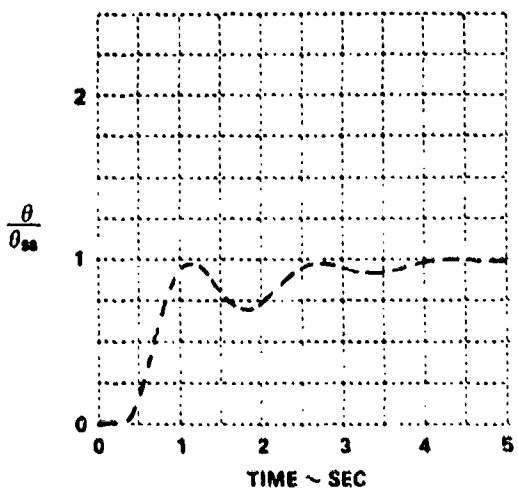
– – – – $\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

2G	CONFIGURATION ω_{sp} = 4.0 ζ_{sp} = 0.70 -/5/15

PLT./PILOT	1053/M
PR/PIOR	7/3
$(F_s/n)/K_\theta$	5.5/0.70
K_p/K_{BW}	1.3/1.5
STICK FORCES	O.K. FORCES SELECTED TO BE A BIT ON THE HEAVY SIDE TO MINIMIZE OVERCONTROL TENDENCIES. NO REAL SECOND THOUGHTS ON GEARING SELECTION; GEARING DIDN'T MAKE A WHOLE LOT OF DIFFERENCE.
PREDICTABILITY OF RESPONSE	VERY POOR. OVERCONTROLLING ALL THE TIME. FORCES SEEM HEAVY INITIALLY - BECOME SOMEWHAT LIGHTER AS RESPONSE DEVELOPS. HAVE TO OVERDRIVE IT SOMEWHAT.
ATTITUDE CONTROL/ TRACKING CAPABILITY	EXTREMELY POOR. TENDENCY TOWARD PIO'S. DIFFICULT TO ACQUIRE A TARGET, AND TAKES A LONG TIME TO SETTLE DOWN ON TARGET.
NORMAL ACCELERATION CONTROL	POOR. OVERSHOOTS DESIRED G, THEN TAKES A LONG TIME TO SETTLE DOWN.
EFFECTS OF RANDOM DISTURBANCES	EMPHASIZES PIO TENDENCIES.
IFR PROBLEMS	TRACKING TASKS EMPHASIZE PIO TENDENCIES.
GOOD FEATURES	NOT MANY. FORCES O.K.
OBJECTIONABLE FEATURES	DIFFICULTY IN ACQUIRING AND TRACKING TARGET. G CONTROL IS VERY POOR; WOULD BE EASY TO OVERSTRESS AIRPLANE.

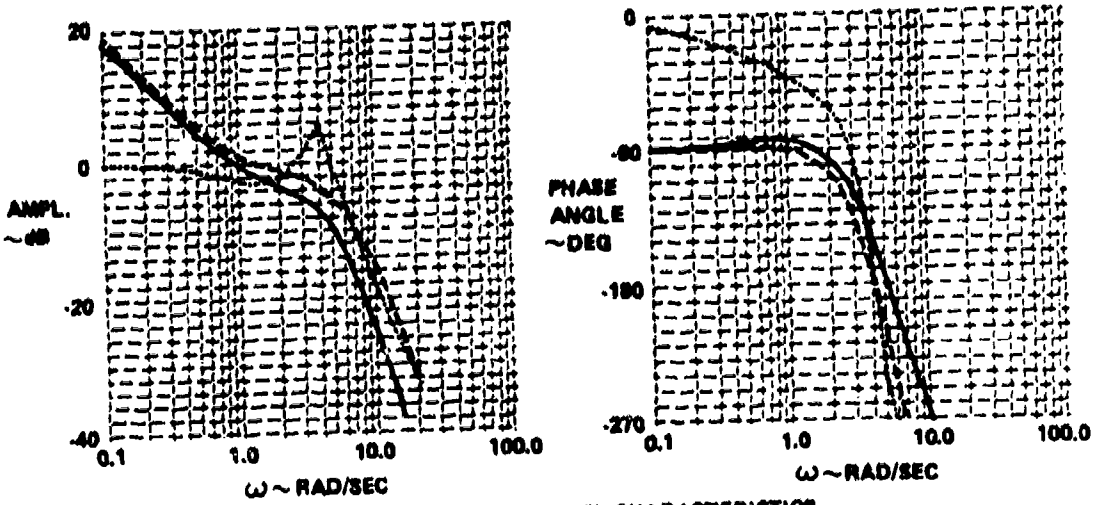
2G

$1/\tau_{\theta_2}$	= 1.25	BW	= 3.0
n/α	= 16.5	χ_{ps}	= +35
V_T	= 480	K_L	= 0.91

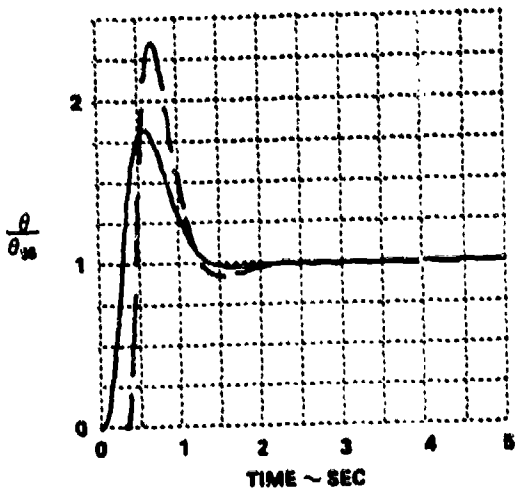
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

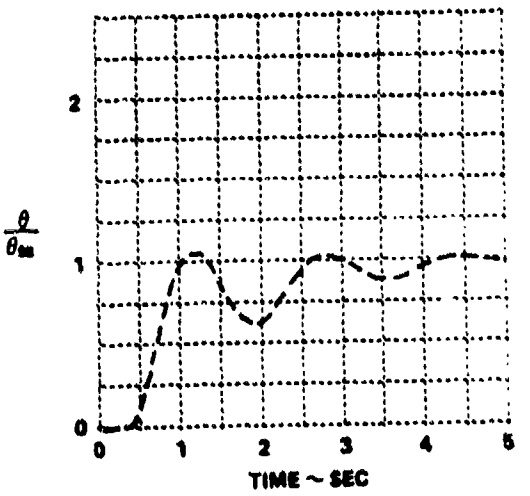
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

2H	CONFIGURATION ω_{sp} = 4.8 ζ_{sp} = 0.70 - / 5 / 63

PLT./PILOT	1022/M	1040/M	1027/W
PR/PIOR	5/2.5	6/2.5	5.5/2
$(F_s/n)/K_{ff}$	8.2/0.47	4.9/0.79	5.7/0.68
K_p/K_{BW}	1.9/3.3	1.1/2.0	1.3/2.3
STICK FORCES	O K NOT MUCH OF A COMPROMISE IN SELECTING GEARING.	COMFORTABLE. HEAVY INITIALLY AND THEN TEND TO LIGHTEN UP NO SECOND THOUGHTS.	STEADY FORCES ARE A BIT HIGH, BUT LIGHTER FORCES WOULD INCREASE TENDENCY TO OVERCONTROL.
PREDICTABILITY OF RESPONSE	FEELS LIKE IT'S DIGGING IN NOT VERY PREDICTABLE. HAVE TO OVERDRIVE TO GET MOVING INITIALLY THEN THE FORCES REQUIRED SEEM TO LIGHTEN, THEN HEAVY UP AGAIN IN THE STEADY STATE	POOR BECAUSE FORCES GO HEAVY TO LIGHT MAKING IT DIFFICULT TO PREDICT FINAL RESPONSE. INITIAL RESPONSE IS PERHAPS A LITTLE SLUGGISH BUT NOT A PROBLEM	DIFFICULT TO PREDICT TENDS TO OVERSHOOT DESIRED G PUT IN AN INPUT THEN HAVE TO LEAD STICK IN OPPOSITE DIRECTION TO STOP AIRPLANE WHERE DESIRED
ATTITUDE CONTROL TRACKING CAPABILITY	ADEQUATE SOME COMPENSATION REQUIRED BECAUSE OF DIFFICULTIES WITH PREDICTABILITY OF RESPONSE.	NOT VERY GOOD.	POOR DOESN'T OSCILLATE ON IT'S OWN BUT IS DIFFICULT TO STOP NOSE AT DESIRED ATTITUDE
NORMAL ACCELERATION CONTROL	TENDS TO OSCILLATE OR OVERSHOOT THE DESIRED G.	OVERSHOOTS IN G CAN PULL MORE ACCURATELY WHEN LOOKING OUTSIDE.	POOR LACK OF INITIAL RESPONSE LEADS TO OVER CONTROL IN G
EFFECTS OF RANDOM DISTURBANCES	DIDN'T UNCOVER ANY NEW PROBLEMS JUST EMPHASIZED THE ONES ALREADY DISCUSSED	NOTHING PARTICULAR HERE	DIDN'T SHOW MUCH
IFR PROBLEMS	TRACKING TASKS SHOWED UP MORE PIO TENDENCIES THAN VFR TASKS TENDENCY TO OVERCONTROL.	PIO TENDENCY COMES TO LIGHT, G OVERSHOOT MORE EVIDENT IFR.	NOT MUCH DIFFERENT FROM VFR
GOOD FEATURES	CAN ADEQUATELY PERFORM ALL TASKS FOR FIGHTER MISSION, BUT NO PARTICULAR OUTSTANDING FEATURES	FORCES ARE ACCEPTABLE, ONCE ON TARGET IT'S PRETTY STEADY.	CONTROL IS GOOD FOR JUST DRIVING AROUND THE SKY SMOOTH AND COMFORTABLE
OBJECTIONABLE FEATURES	SLIGHT DIFFICULTY WITH PREDICTABILITY OF RESPONSE TENDENCY TO OSCILLATE AROUND TARGET	PIO TENDENCY ON TARGET, POOR G CAPABILITY. NOT PRECISE. DIFFICULT TO ACQUIRE A TARGET	OVERCONTROL DURING TRACKING

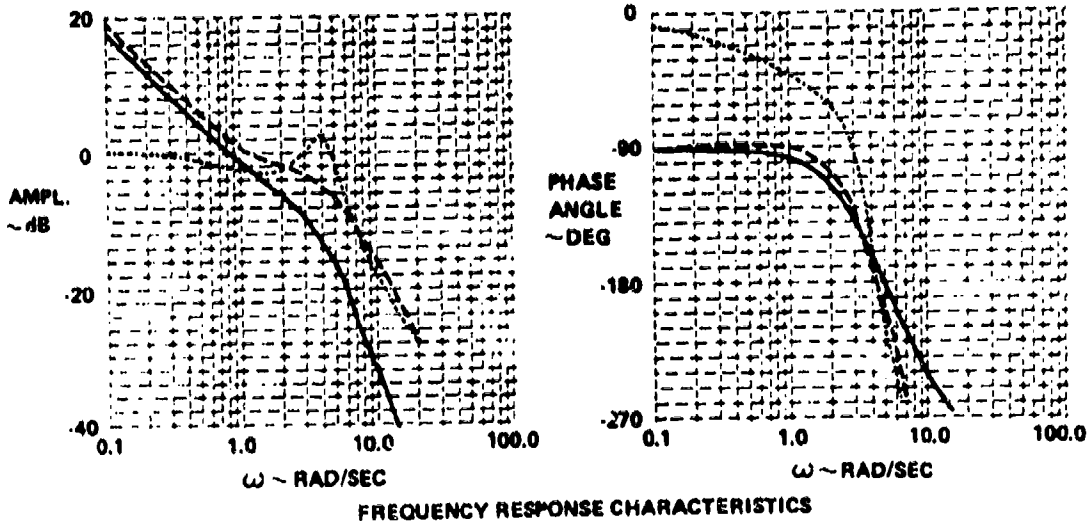
2 H

$1/\tau_{\theta_2}$	= 1.25	BW	= 3.0
n/α	= 18.5	Δ_{pc}	= +55
V_T	= 480	K_L	= 0.87

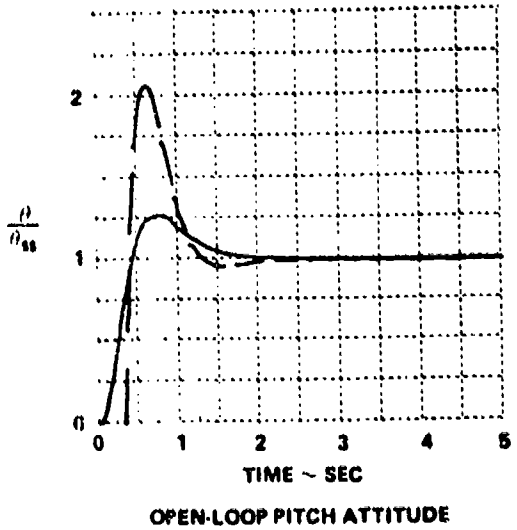
——— $\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

— — — $\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

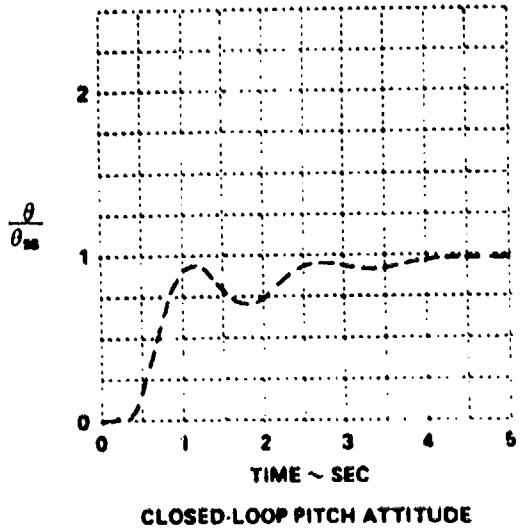
– – – – $\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



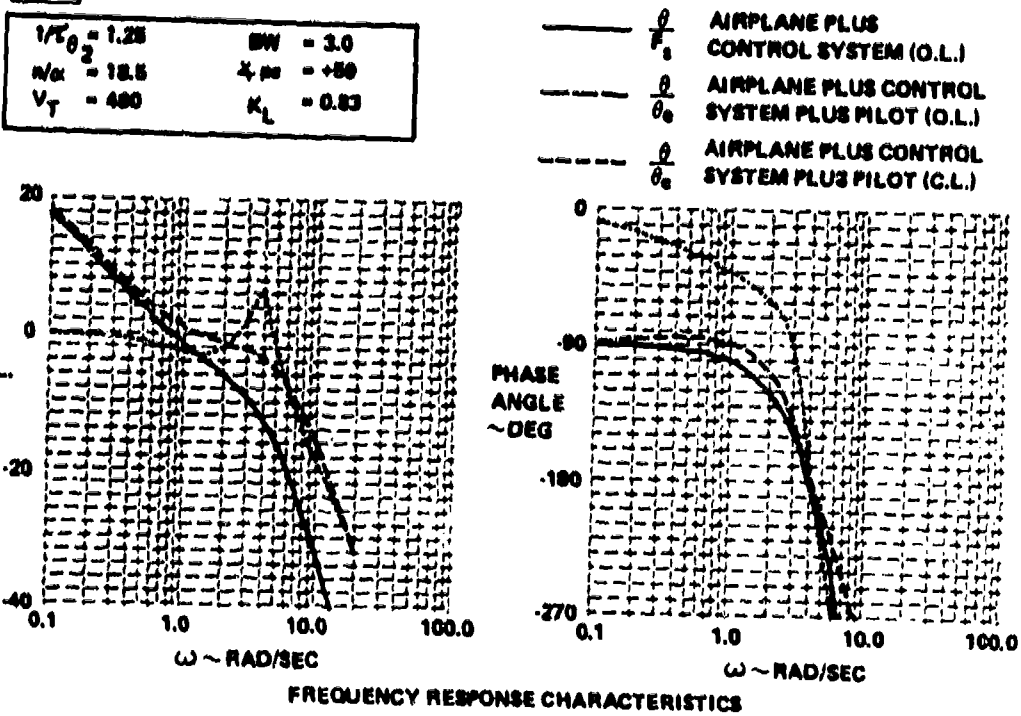
CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

21	CONFIGURATION ω_{sp} = 4.0 ζ_{sp} = 0.70 -/ 2 / 16

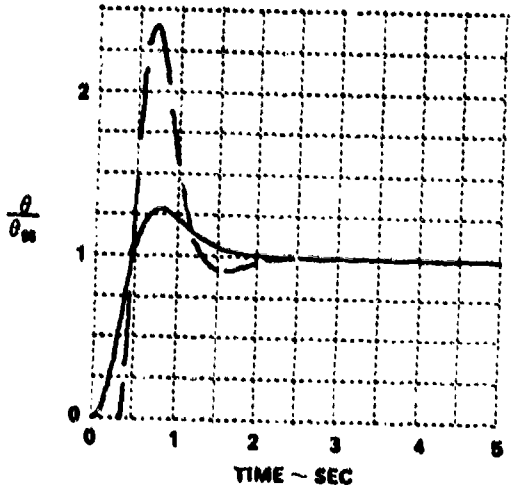
FLT./PILOT	1036/M	1036/W
PR/PIOR	6/4.5	6/4
$(F_e/n)/K_\theta$	4.6/0.84	4.6/0.76
K_p/K_{SW}	1.6/2.6	1.1/2.2
STICK FORCES	HEAVY ? LIGHT FORCES. COULD G _ LIGHT WITHOUT COMPROMISING TRACKING ABILITY. WERE NICE BUT PERHAPS SHOULD HAVE BEEN HEAVIER AS GOOD PIO WAS ENCOUNTERED.	SATISFACTORY, NO SECOND THOUGHTS. SELECTION WAS A COMPROMISE, ON THE HEAVY SIDE, TO MINIMIZE PIO TENDENCY.
PREDICTABILITY OF RESPONSE	POOR. BUT CAN LEARN TO COMPENSATE SO AS NOT TO OVERSTRESS IT. HEAVY INITIAL FORCES THEN LIGHTENING UP IN A PECULIAR WAY.	VERY, VERY POOR LARGE LAG THEN AIRPLANE TAKES OFF. FINAL RESPONSE IS POOR BECAUSE OF OVERSHOOT VERY DIFFICULT TO FLY.
ATTITUDE CONTROL/ TRACKING CAPABILITY	NOT VERY GOOD. THE HARDER YOU TRY THE LONGER IT TAKES TO GET ON TARGET.	VERY, VERY POOR. PIO'S RESULT FROM ANY ATTEMPT AT TIGHT TRACKING.
NORMAL ACCELERATION CONTROL	NOT GOOD: VERY OSCILLATORY ABOUT THE DESIRED G.	LIKEWISE, POOR. CAN HOLD THE G ONCE ESTABLISHED BY SMOOTH USE OF CONTROLS.
EFFECTS OF RANDOM DISTURBANCES	TENDED TO EMPHASIZE THE PIO TENDENCY	BARELY NOTICEABLE
IFR PROBLEMS	VERY DRAMATIC PIO PROBLEMS IN RN TRACKING TASK SNEAKS UP ON YOU - HAD TO LET GO OR LOSE CONTROL. DIDN'T HAVE THIS PROBLEM IN D.E. TRACKING TASK.	NOTHING NEW. D E TRACKING TASK SHOWED UP PIO TENDENCIES. RN TRACKING TASK SHOWED UP PIO PROBLEM ALSO, BUT TO A LESSER DEGREE.
GOOD FEATURES	HAS A CERTAIN STABILITY ON TARGET BUT MUST BE FLOWN VERY SMOOTHLY TO GET THERE FORCES ARE PLEASANT	TRIM CAPABILITY. G IN MANEUVERING GOOD.
OBJECTIONABLE FEATURES	INSIDIOUS TENDENCY TOWARD PIO'S A REAL SLEEPER. CHANGE OF FORCES WITH G APPLICATION	TENDENCY TOWARDS PIO WHEN TIGHT TRACKING ATTEMPTED LARGE INITIAL RESPONSE DELAY.

21

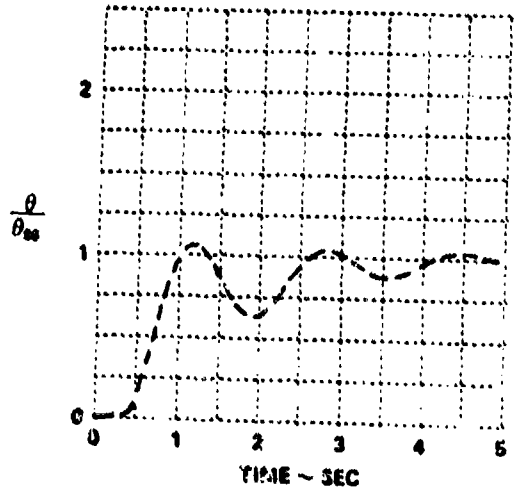
$1/T_{\theta_2}$	= 1.25	BW	= 3.0
n/α	= 18.5	ζ_{ps}	= +.59
V_T	= 480	K_L	= 0.83



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

2J	CONFIGURATION ω_{sp} = 4.9 ζ_{sp} = 0.70 -/0.5/63

PLT /PILOT	1063/M	1060/W
PR/PICR	6/2	6/2
$(\theta_\delta/n)/K_{(}$	5.5/0.70	4.8/0.75
K_θ $K_{\theta W}$	1.5/7.4	1.3/6.8
STICK FORCES	SELECTED THE STEADY FORCES LIGHT TO KEEP THE INITIAL FORCES DOWN, BUT MAYBE SHOULD HAVE SELECTED THEM A BIT LIGHTER YET	WOULD HAVE LIKED SOMEWHAT LIGHTER FORCES, BUT FORCES USED WERE LIGHTEST ALLOWED. FORCES WERE ACCEPTABLE HOWEVER, AND NOT TOO BOTHERSOME.
PREDICTABILITY OF RESPONSE	VERY POOR. FORCES ARE INITIALLY HEAVY, THEN LIGHTEN RAPIDLY AS RESPONSE DEVELOPS. HAVE TO OVERDRIVE IT	AIRPLANE RESPONSE IS VERY SLOW. HAVE TO USE LARGE INITIAL INPUT, THEN TAKE IT OUT IMMEDIATELY. EVEN THEN, IT IS DIFFICULT TO STOP AT DESIRED STEADY STATE
ATTITUDE CONTROL TRACKING CAPABILITY	YOU HAVE TO OVERDRIVE IT (HEAVY INITIAL FORCES) TO ACQUIRE A TARGET, AND EVEN THEN IT IS DIFFICULT TO AVOID OVERCONTROL. RELATIVELY STEADY ON TARGET THOUGH.	POOR. TAKES LONG TIME TO CHANGE ATTITUDE, AND NOT VERY PRECISE.
NORMAL ACCELERATION CONTROL	BAD. HAVE TO OVERDRIVE IT TO GET IT MOVING. VFR, YOU CAN LEARN TO DO A CREDIBLE JOB	OVERSHOOTS IF YOU TRY TO RAPIDLY AND ACCURATELY ACQUIRE G, BUT RELATIVELY GOOD IF YOU EASE ON THE G.
EFFECTS OF RANDOM DISTURBANCES	TOOK LARGE FORCES AND A GREAT DEAL OF EFFORT TO GET BACK ON TARGET AFTER EACH DISTURBANCE	MAKES TRACKING VERY DIFFICULT.
IFR PROBLEMS	D E TRACKING TASK OFTEN CAUSED SOME PIO'S RN TRACKING TASK SHOWED NOTHING NEW, BUT WAS HARD WORK	NO NEW PROBLEMS
GOOD FEATURES	COULD PULL LIMIT LOAD FACTOR WITHOUT EXCESSIVE FORCES. PRETTY STEADY ON TARGET	GOOD OVERALL MANEUVERABILITY IF FLOWN SMOOTHLY
OBJECTIONABLE FEATURES	EXTREMELY HIGH INITIAL FORCES. HAVE TO OVERDRIVE IT. DIFFICULT TO ACQUIRE A TARGET. PIO PROBLEMS ON D E TRACKING TASK	VERY SLOW INITIAL RESPONSE AND TENDENCY TO OVERCONTROL.

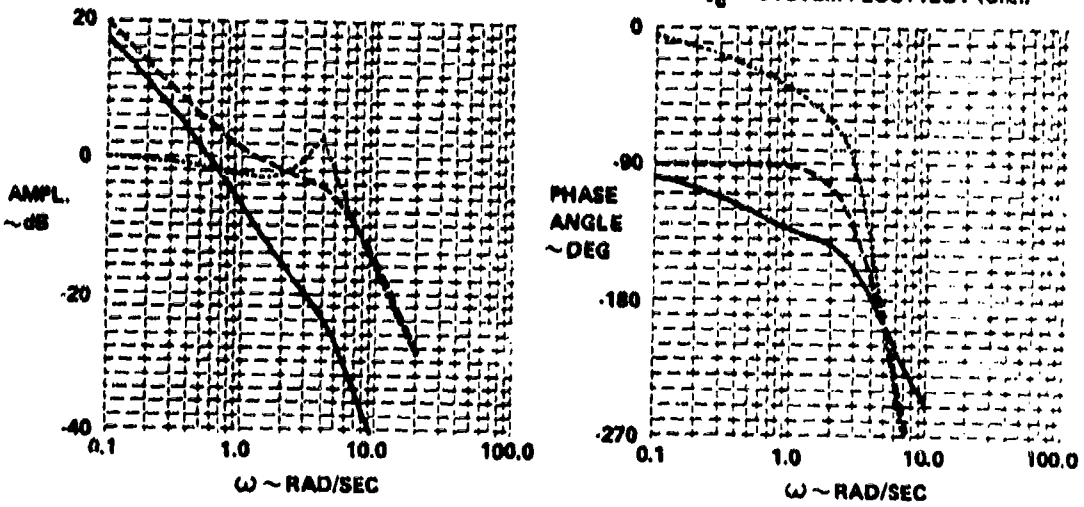
2 J

$1/T_{\theta_2}$ = 1.25	BW = 3.0
n/α = 18.5	$\angle_{ps}$ = +78
V_T = 480	K_L = 1.03

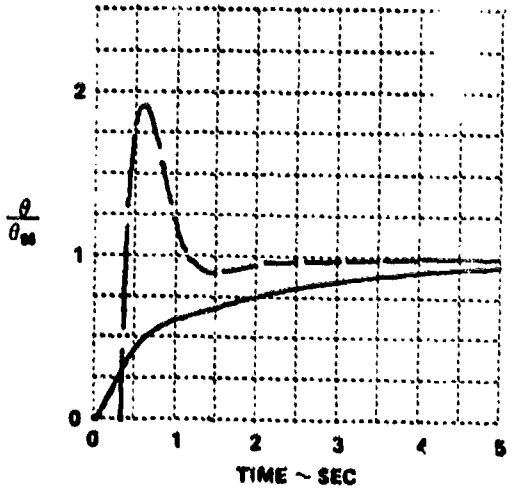
——— $\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

– – – $\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

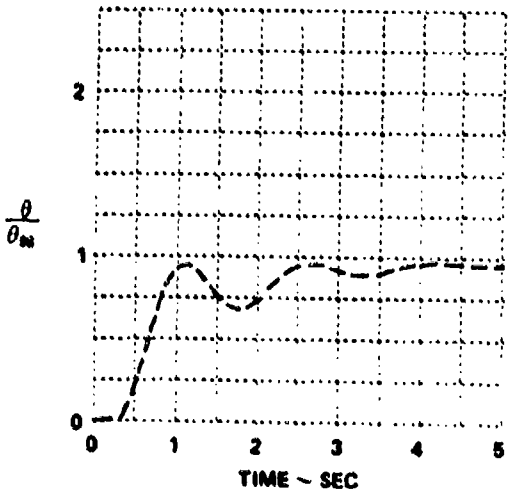
– – – – $\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

3A

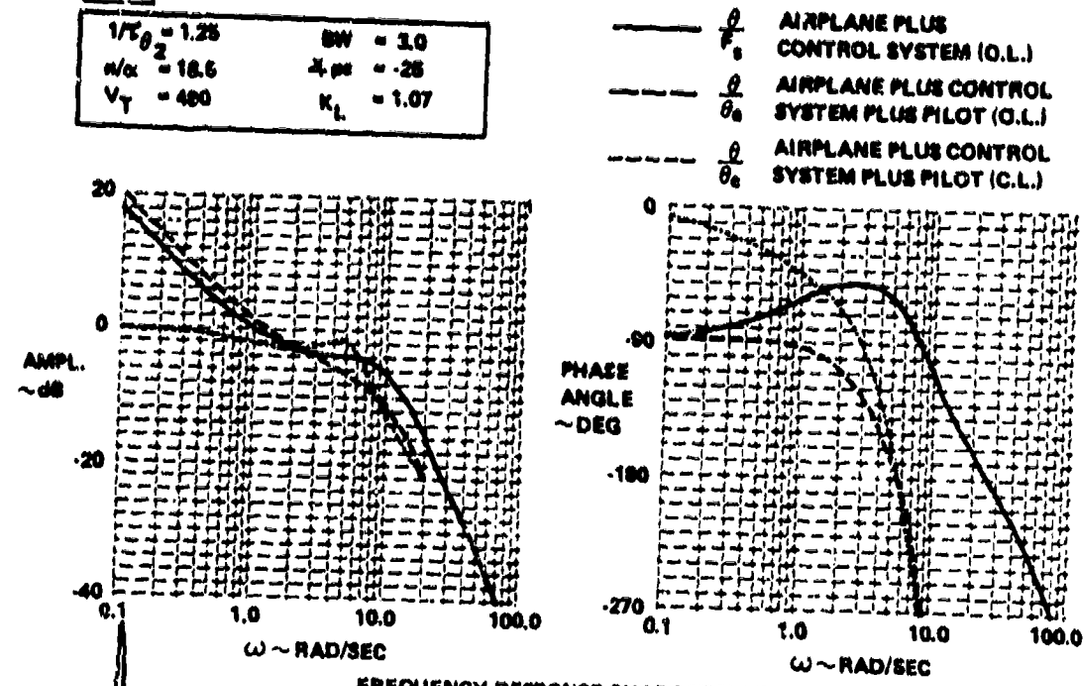
CONFIGURATION
ω_{sp} = 9.7 ζ_{sp} = 0.68
- / - /75

FLT./PILOT	1088/N	1044/N	1084/W	1073/W
PR/PIOR	9/3	4/1.5	4/1	4/1.5
[illegible]	10.8/0.38	5.4/0.71	11.5/0.33	5.7/0.67
[illegible]	3.0/2.0	1.5/0.67	3.3/2.1	1.0/1.0
STICK FORCES	COMPROMISE BETWEEN STEADY FORCES AND SENSITIVITY	ON THE HEAVY SIDE ON PURPOSE BECAUSE AIR PLANE IS TOO RESPONSIVE INITIAL FORCES STILL QUITE LIGHT	COMPROMISE BETWEEN STEADY FORCES AND SENSITIVITY IN SELECTING GEARING, BUT SELECTED FORCES ARE GOOD	QUITE REASONABLE NOT SECOND THOUGHTS ON GEARING SELECTION
PREDICTABILITY OF RESPONSE	DIFFICULT TO PREDICT INITIALLY ABRUPT.	GOOD AS FAR AS G GOES. CONTINUALLY OVERSHOT THE TARGET FOR VISUAL TRACKING AND ALSO IFR SO NOT GOOD FOR PITCH ATTITUDE HOLD STICK VERY LIGHTLY IN MY HAND	NOSE MOVES RIGHT AWAY GOOD BUT G TENDS TO OVERSHOOT, THEN DROP BACK BELOW DESIRED STEADY STATE	NOT OUTSTANDING, BUT GOOD INITIAL RESPONSE IS QUITE SNAPPY MAYBE A LITTLE TOO SNAPPY FOR A FIGHTER. A LITTLE DIFFI CULTY IN DECIDING WHERE AIRPLANE IS GOING TO STOP, BUT FINAL RESPONSE IS GOOD
ATTITUDE CONTROL: TRACKING CAPABILITY	CONSIDERABLE OSCILLA TION ON TARGET MUST BACK OFF ON GAIN WHEN ON TARGET	IN ACQUIRING A TARGET THERE IS ALWAYS ONE, MAYBE TWO, OVERSHOOTS. NOT GOOD	GOOD, BUT NOT OUTSTAND ING. OSCILLATED ON TARGET INITIALLY, BUT LEARNED TO FLY SMOOTHLY WITH PRACTICE	QUITE GOOD. HAVE TO FLY IT SOMEWHAT GINGERLY, BUT THIS MAY BE DUE TO STRUCTURAL OSCILLATIONS
NORMAL ACCELERATION CONTROL	GOOD	PRETTY GOOD BUT A LITTLE TOU RESPONSIVE.	NOT QUITE AS GOOD AS DESIRED G TENDS TO OVER SHOOT, THEN DROP BACK BELOW DESIRED STEADY STATE TECHNIQUE HELPED TO HOLD G RELATIVELY WELL	GOOD
EFFECTS OF RANDOM DISTURBANCES	NO NEW PROBLEMS SIMPLY ACCENTUATED SMOOTH AIR PROBLEMS	A PROBLEM LEADS TO OVERCONTROLLING AND INCREASING THE DISTURB ANCES	WHEN DISTURBANCE MOVES NOSE OFF TARGET, A SERIES OF SMALL ATTITUDE COR RECTIONS ARE REQUIRED TO AVOID OVERCONTROL THIS IS DIFFICULT	A BIT NOTICEABLE
IFR PROBLEMS	NO NEW PROBLEMS.	TENDENCY TO OVERSHOOT ON D E TRACKING TASK	IFR IS DIFFICULT BECAUSE OF SMALL, PRECISION MANEUVERS REQUIRED TENDENCY TO BOBBLE	NO NEW PROBLEMS
GOOD FEATURES	GOOD NORMAL ACC ELERATION CONTROL	RESPONSIVE, CAN PULL G QUITE ACCURATELY	GOOD FOR MANEUVERING. GOOD FOR TRACKING. OVERALL.	MANEUVERING CHARAC TERISTICS ARE GOOD ATTITUDE CONTROL AND TRACKING CAPABILITY ARE GOOD, BUT NOT OUTSTAND ING
OBJECTIONABLE FEATURES	TRADE OFF ON FORCES BOBBLING ON TARGET FOR PRECISE CORRECTIONS	TOO RESPONSIVE, COUPLED WITH LIGHT INITIAL FORCES LEADS TO UNWANTED INPUTS TEND TO BOBBLE ON TARGET EVEN WITH STEADY FORCES AS HEAVY AS PERMISSIBLE	MINOR TENDED TO BE SENSITIVE FOR SMALL RAPID MANEUVERS GOT BETTER WITH PRACTICE	NO OUTSTANDING OBJEC TIONS JUST A FEELING THAT A FIGHTER DOES NOT HAVE TO RESPOND THAT FAST

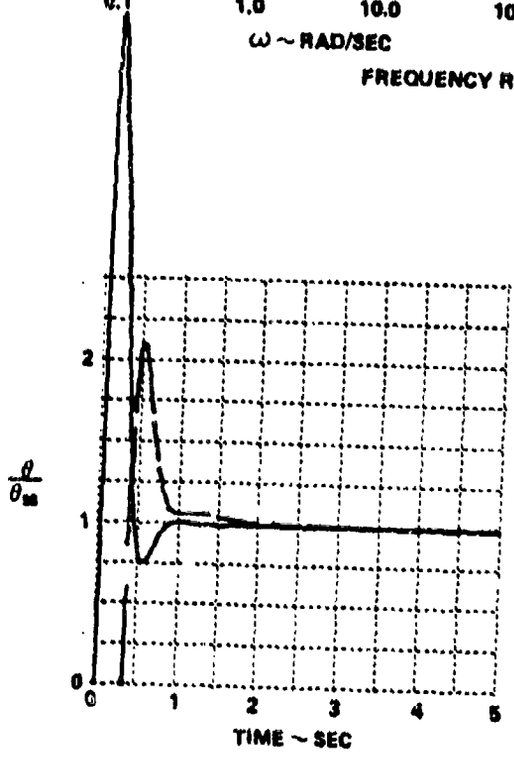
NOTE THE PRESENCE OF HIGH FREQUENCY STRUCTURAL OSCILLATIONS IN THIS CONFIGURATION MAY HAVE INFLUENCED THE MANNER IN WHICH THE FIGHTER TASK WAS FLOWN AND THEREFORE THE PILOT RATING

3 A

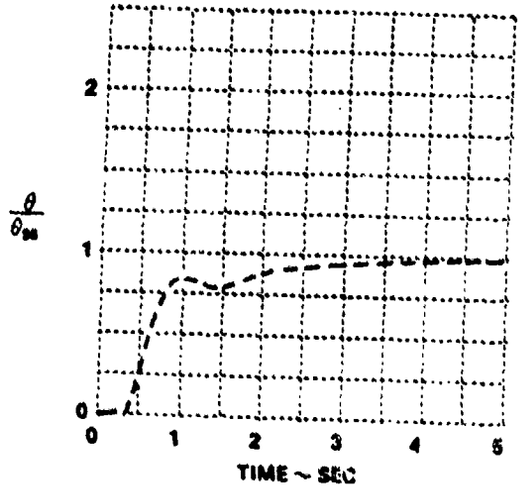
$1/T_{\theta_2}$	= 1.25	BW	= 3.0
n/α	= 18.6	Δ_{ps}	= -.28
V_T	= 480	K_L	= 1.07



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

38	CONFIGURATION ω_{sp} = 0.7 ζ_{sp} = 0.63 -/12/63

FLT./PILOT	1048/M
PR/PIOR	4.5/2
$(F_s/n)/K_\theta$	4.3/0.89
K_p/K_{BW}	1.0/0.83
STICK FORCES	GOOD. NO SECOND THOUGHTS ON GEARING SELECTION. NO SERIOUS COMPROMISES IN-VOLVED IN SELECTION.
PREDICTABILITY OF RESPONSE	NOT TOO GOOD TENDENCY TO OVERCONTROL IN ATTI TUDE USE SMOOTH INPUTS
ATTITUDE CONTROL/ TRACKING CAPABILITY	TENDENCY TO INITIALLY OVERSHOOT TARGET, THEN ONE OR TWO BOBBLES IN GETTING SETTLED DOWN
NORMAL ACCELERATION CONTROL	QUITE GOOD.
EFFECTS OF RANDOM DISTURBANCES	NO PROBLEMS
IFR PROBLEMS	NO APPRECIABLE DIFFER ENCES FROM VFR
GOOD FEATURES	LIGHT FORCES GOOD FOR MANEUVERING CAN ACQUIRE A TARGET (SOME PROBLEMS)
OBJECTIONABLE FEATURES	BOBBLING TENDENCIES ON TARGET DIFFICULTIES IN ACQUIRING AND HOLDING TARGET

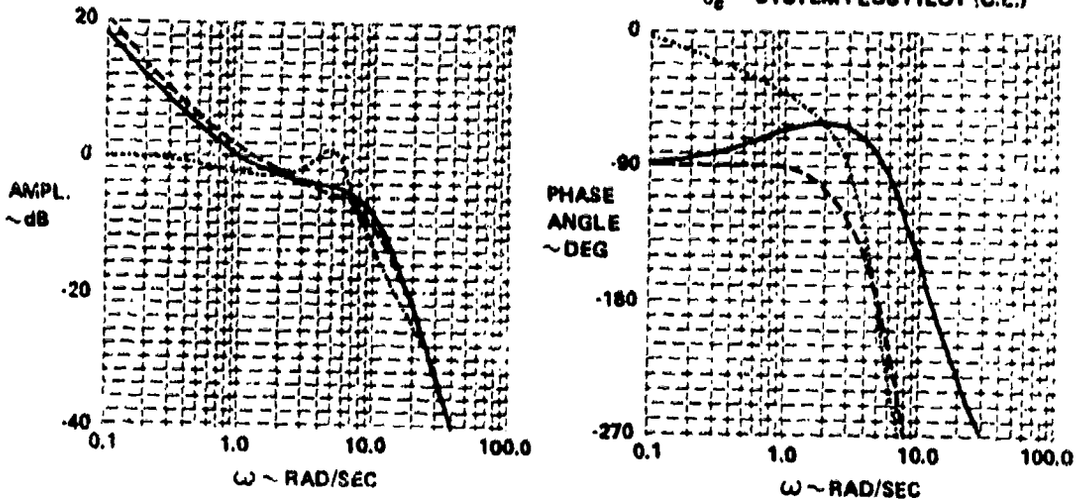
3B

$1/T_{\theta_2}$	= 1.25	BW	= 3.0
n/α	= 18.5	ϕ_{pc}	= -12
V_T	= 480	K_L	= 0.92

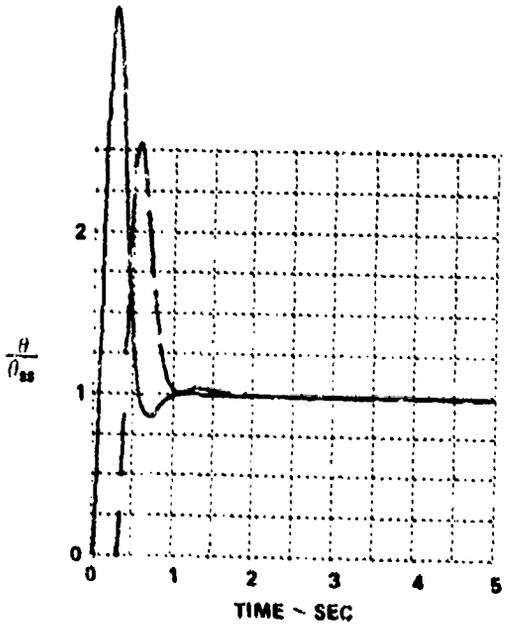
——— $\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

– – – $\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

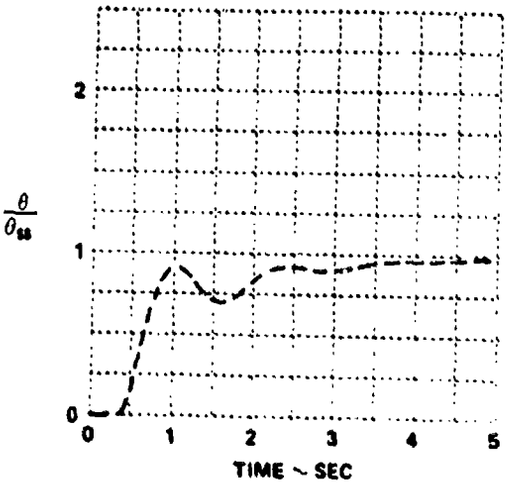
– – – $\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

3C	CONFIGURATION ω_{sp} = 9.7 ζ_{sp} = 0.63 -/ 6 /0.3

FLT./PILOT	1636/M	1066/W
PR/PIOR	4/2	3/1
$(F_s/n)/K_\theta$	1.2/0.53	5.1/0.75
K_θ/K_{SW}	1.7/1.7	1.2/1.2
STICK FORCES	PROBABLY A LITTLE ON THE HEAVY SIDE BUT NO SECOND THOUGHTS. IN.TIAL FORCES COMPATIBLE WITH STEADY STATE FORCES.	O.K. COULD HAVE USED LIGHT ER FORCES, BUT FORCES SELECTED WERE QUITE SATISFACTORY. REALLY NO COMPROMISE INVOLVED IN GEARING SELECTION.
PREDICTABILITY OF RESPONSE	WAS GOOD.	PRETTY GOOD. MINOR OBJEC TIONS. SLIGHT TENDENCY TO DIG IN. OVERSHOOTS ONCE IN ACQUIRING A TARGET CAN'T GET RID OF IT.
ATTITUDE CONTROL/ TRACKING CAPABILITY	TENDENCY TO BOBBLE ON TARGET. 2 OR 3 OVERSHOOTS, HOWEVER COULD GET ON TARGET IN AN ACCEPTABLE LENGTH OF TIME.	PRETTY GOOD. DIGS IN INITIALLY, THEN OVERSHOOTS TARGET ONCE.
NORMAL ACCELERATION CONTROL	QUITE ADEQUATE; SMALL AMPLITUDE BOBBLING.	VERY GOOD.
EFFECTS OF RANDOM DISTURBANCES	DIDN'T SHOW UP ANYTHING NEW.	NOTICEABLE, BUT DID NOT CAUSE ANY PROBLEMS
IFR PROBLEMS	BETTER IFR THAN VFR. NO BOBBLE APPARENT; THINK THE PRECISION REQUIRED FOR VFR IS GREATER THAN FOR IFR.	NO NEW PROBLEMS. PRETTY GOOD.
GOOD FEATURES	QUITE MANEUVERABLE.	MANEUVER CAPABILITY AND G CONTROL VERY GOOD. TRACKING CAPABILITY IS GOOD
OBJECTIONABLE FEATURES	FINITE TIME REQUIRED TO SETTLE DOWN ON A TARGET. SLIGHT OSCILLATION IN STEADY STATE G	MINOR DIGS IN ONE OVER SHOOT ON TARGET

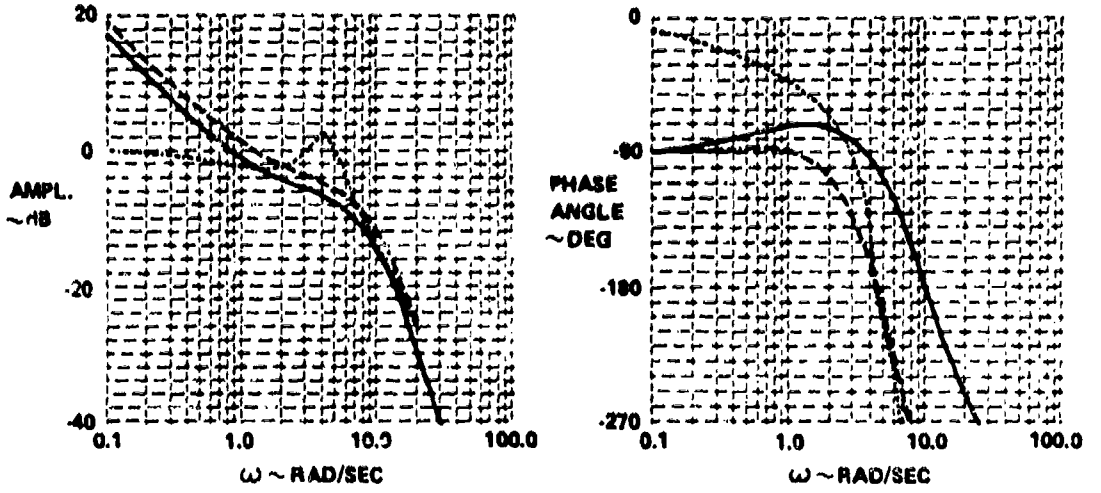
3 C

$1/\tau_{\theta_2}$	= 1.25	BW	= 3.0
n/α	= 18.5	ζ_{ps}	= 0
V_T	= 480	K_L	= 0.91

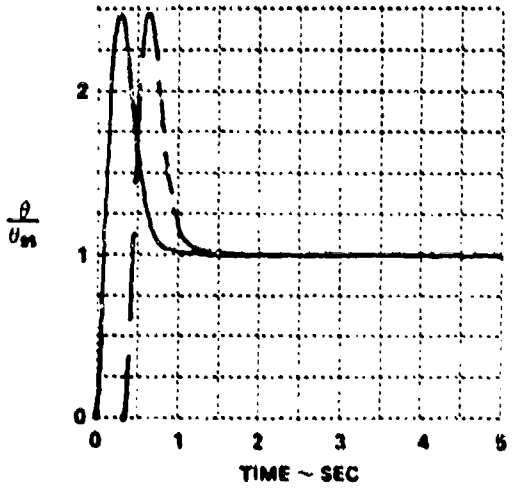
——— $\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

– – – $\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

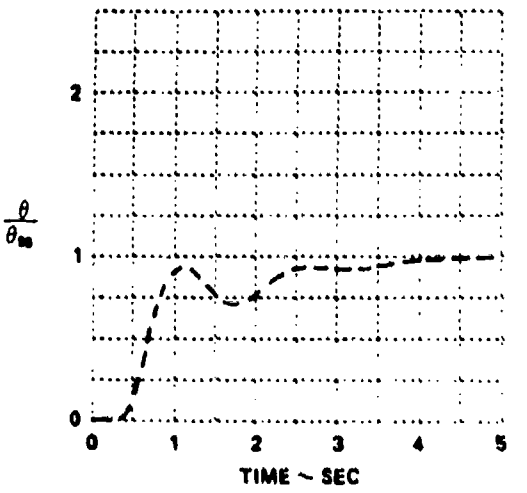
– · – · – $\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

3D	CONFIGURATION ω_{sp} = 0.7 ζ_{sp} = 0.63 – 1 2 / 63

FLT./PILOT	1068/M	1068/W
PR/PIOR	4/2	4/1
$(F_s/n)/K_\theta$	S 1/0 75	S 4/0.71
K_p/K_{BW}	1.4/1 7	1.6/1.8
STICK FORCES	PRETTY GOOD. A LITTLE HEAVY, PERHAPS. NO SECOND THOUGHTS ABOUT GEARING SELECTION.	NOT OUTSTANDING, BUT O K. A LITTLE HEAVY, BUT SELECTED THAT WAY TO REDUCE TENDENCIES FOR OVERCONTROL. NO SECOND THOUGHTS ON GEARING SELECTION
PREDICTABILITY OF RESPONSE	A BIT OF A PROBLEM. STICK FORCES LIGHTEN AS THE RESPONSE DEVELOPS, LEADING TO SMALL PROBLEMS IN ATTITUDE AND G CONTROL.	A LITTLE DIFFICULT. THE AIRPLANE HAS A VERY SLOW RESPONSE, WHICH MEANS THAT YOU HAVE TO PUT IN A VERY LARGE INPUT INITIALLY AND THEN RAPIDLY CHECK IN THE OPPOSITE DIRECTION TO STOP THE NOSE WHERE YOU WANT IT
ATTITUDE CONTROL TRACKING CAPABILITY	GET ONE RELATIVELY LARGE OVERSHOOT, FOLLOWED BY ONE OR TWO SMALLER ONES, IN ACQUIRING A TARGET PRETTY STEADY ON TARGET THOUGH	FAIR. TAKES A LOT OF EFFORT TO CHANGE ATTITUDE ACCURATELY AND THERE IS USUALLY ONE SMALL OVERSHOOT INVOLVED
NORMAL ACCELERATION CONTROL	A BIT OF PROBLEM TO PULL G QUICKLY AND ACCURATELY. ONE OR TWO OVERSHOOT., VFR WORSE IFR	QUITE GOOD FOR GROSS MANEUVERING. PUT OVER SHOOTS IF TRYING TO ACQUIRE A GIVEN G PRECISELY
EFFECTS OF RANDOM DISTURBANCES	NO NEW PROBLEMS	HAD QUITE A NOTICEABLE EFFECT, ESPECIALLY IN TRACKING
IFR PROBLEMS	AIRPLANE IS WORSE IFR THAN VFR. OSCILLATES SEVERAL TIMES ABOUT DESIRED ATTITUDE ON D E TRACKING TASK	NO NEW PROBLEMS. IFR TRACKING ABILITY WAS ACTUALLY QUITE GOOD
GOOD FEATURES	COMFORTABLE STICK FORCES. STEADY ON TARGET. GOOD FOR GROSS MANEUVERING	GOOD FOR GROSS MANEUVERING
OBJECTIONABLE FEATURES	HAVE TO COMPENSATE A LITTLE TO ACQUIRE A TARGET. SOME OSCILLATION IN PULLING G ACCURATELY	SLOW INITIAL RESPONSE AND NEED TO FORCE THE RESPONSE

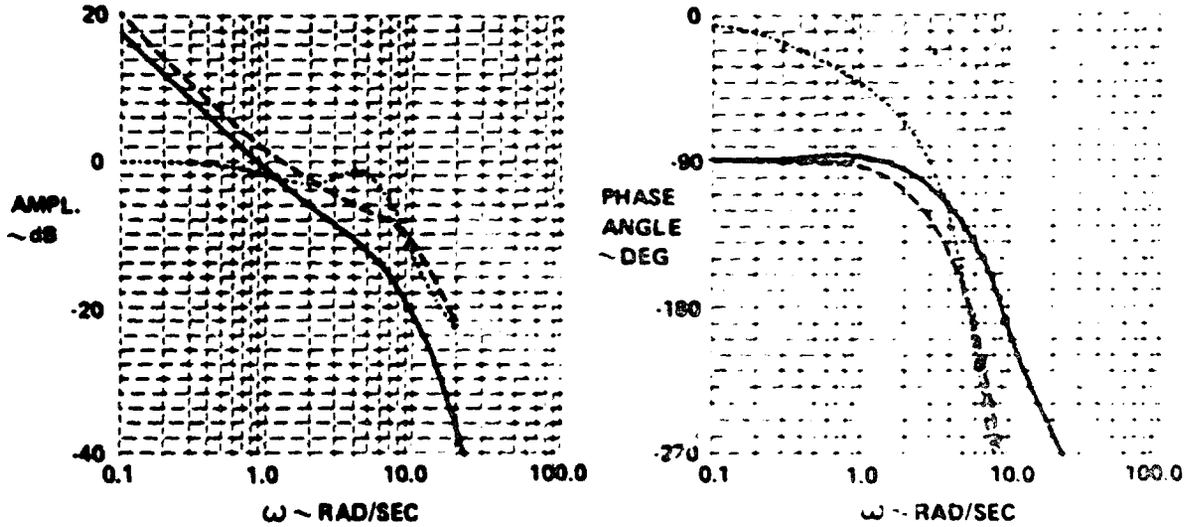
3 D

$1/\tau_{\theta_2}$	= 1.25	BW	= 3.0
n/α	= 18.5	Δ_{ps}	= +31
V_T	= 480	K_L	= 1.06

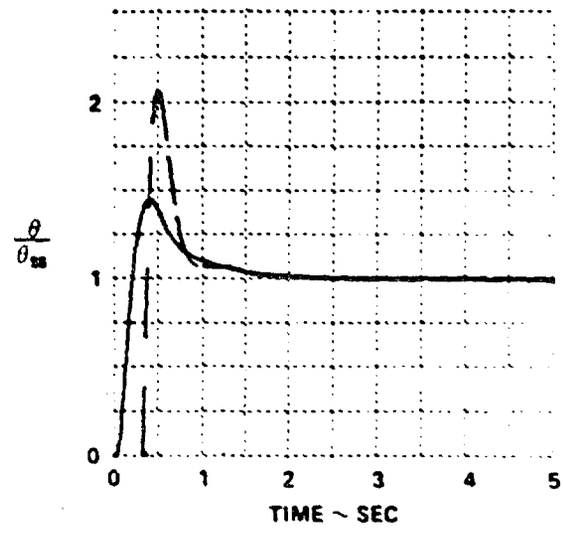
——— $\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

– – – $\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

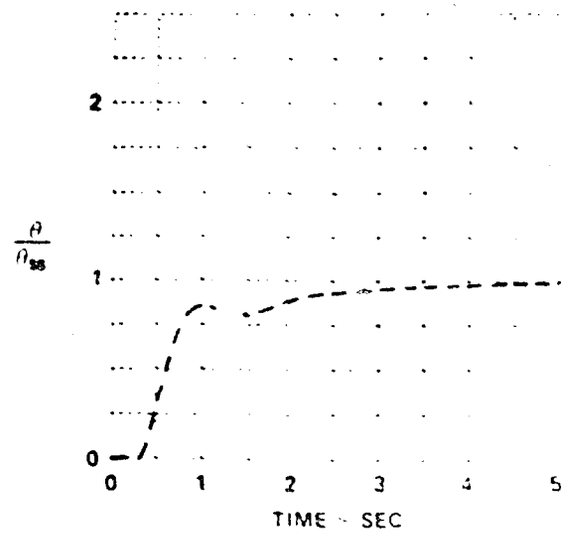
– – – – $\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



CLOSED LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

3 E	CONFIGURATION ω_{sp} = 9.7 ζ_{sp} = .663 - / 0 5 / 6 3

FLT./PILOT	1063/M	1061/W
PR/PIOR	4/1 5	4/1
$(F_s/n)/K_\theta$	4 8/0 80	4 6/0.86
K_θ/K_{SW}	2 9/5 1	2 7/4.8
STICK FORCES	O K FORCES GO FROM HEAVY TO LIGHT AS RESPONSE DEVELOPS MIGHT HAVE SELECTED LIGHTER FORCES EXCEPT THAT STEADY FORCES WOULD GET TOO LIGHT NO SECOND THOUGHTS ON GEARING SELECTION	WOULD LIKE SOMEWHAT LIGHTER BUT GEARING SELECTED WAS THE LIGHTEST ALLOWED FORCES ARE CERTAINLY ADEQUATE AND NOT TOO BAD
PREDICTABILITY OF RESPONSE	A LITTLE PROBLEM, BUT NOT TOO BAD FORCES GO FROM HEAVY TO LIGHT AND IT FEELS LIGHT ON TARGET	QUITE GOOD SLIGHT HESI TATION IN INITIAL RESPONSE WHICH CAUSES YOU TO PULSE THE AIRPLANE SOMEWHAT, BUT NO REAL PROBLEM
ATTITUDE CONTROL/ TRACKING CAPABILITY	PRETTY GOOD COULD AC QUIRE A TARGET RAPIDLY, ALTHOUGH THERE WAS A SMALL TENDENCY TO OVER- SHOOT NOT REAL STEADY ON TARGET	GOOD CAN STOP NOSE PRETTY MUCH WHERE YOU WANT IT ALTHOUGH YOUR PRECISION IS SOMEWHAT DEPENDENT ON HOW WELL YOU JUDGE THE INITIAL INPUT
NORMAL ACCELERATION CONTROL	QUITE GOOD SMALL OSCILLA TION WHEN TRYING TO RAPIDLY ACQUIRE G	GOOD
EFFECTS OF RANDOM DISTURBANCES	HAVE TO WORK TO KEEP NOSE ON TARGET WITH RN DISTURB ANCES BECAUSE OF HEAVY INITIAL FORCES	NOTICEABLE EFFECTS, BUT NO REAL DEGRADATION OF FLYING QUALITIES.
IFR PROBLEMS	GOOD AIRPLANE IFR. NO NEW PROBLEMS.	NO NEW PROBLEMS. TOOK SOME EFFORT TO FOLLOW D. E. TRACKING TASK.
GOOD FEATURES	PRETTY GOOD FIGHTER. QUITE MANEUVERABLE NOT TOO BAD FOR TRACKING	TRACKING CAPABILITY IS NOT OUTSTANDING, BUT IS GOOD. G CONTROL IS ALSO GOOD.
OBJECTIONABLE FEATURES	NOT AS STEADY ON TARGET AS DESIRED SMALL OSCIL LATION IN ACQUIRING G	CAN'T FLY AIRPLANE AS AGGRESSIVELY AS WOULD HAVE LIKED BECAUSE OF INITIAL DELAY

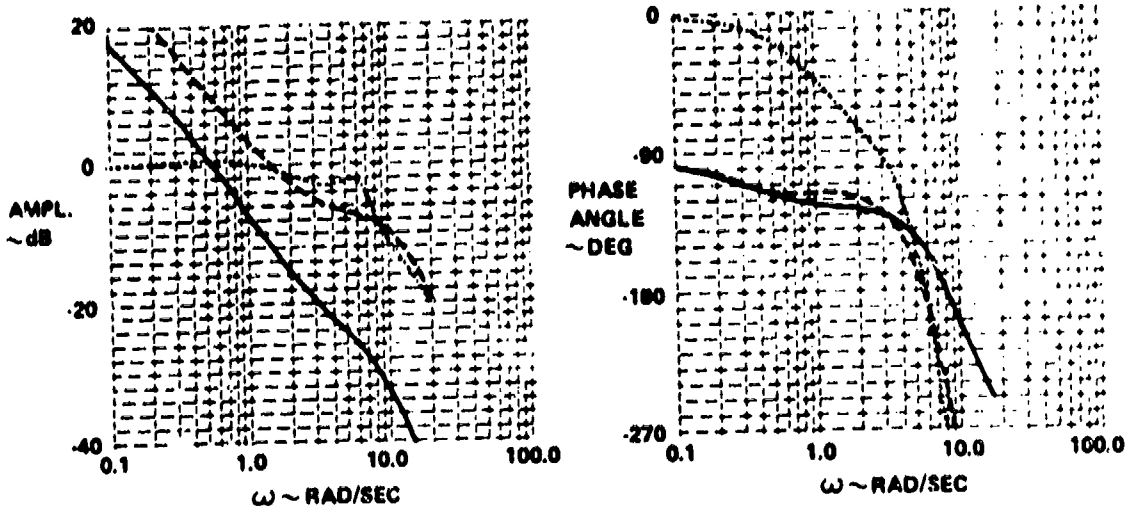
3 E

$1/T_{(\theta_1)_2}$	= 1.25	BW	= 3.0
n/α	= 18.5	Δ_{ps}	= .68
V_T	= 480	K_L	= 2.28

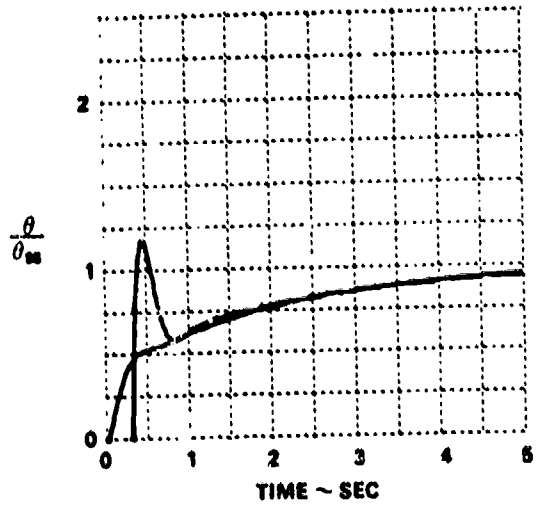
$\frac{\phi}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

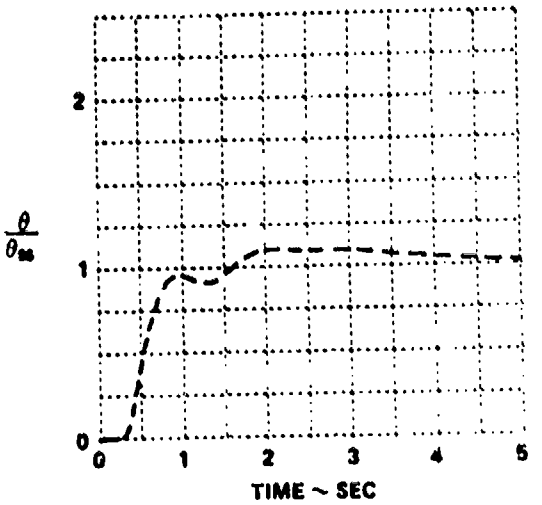
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



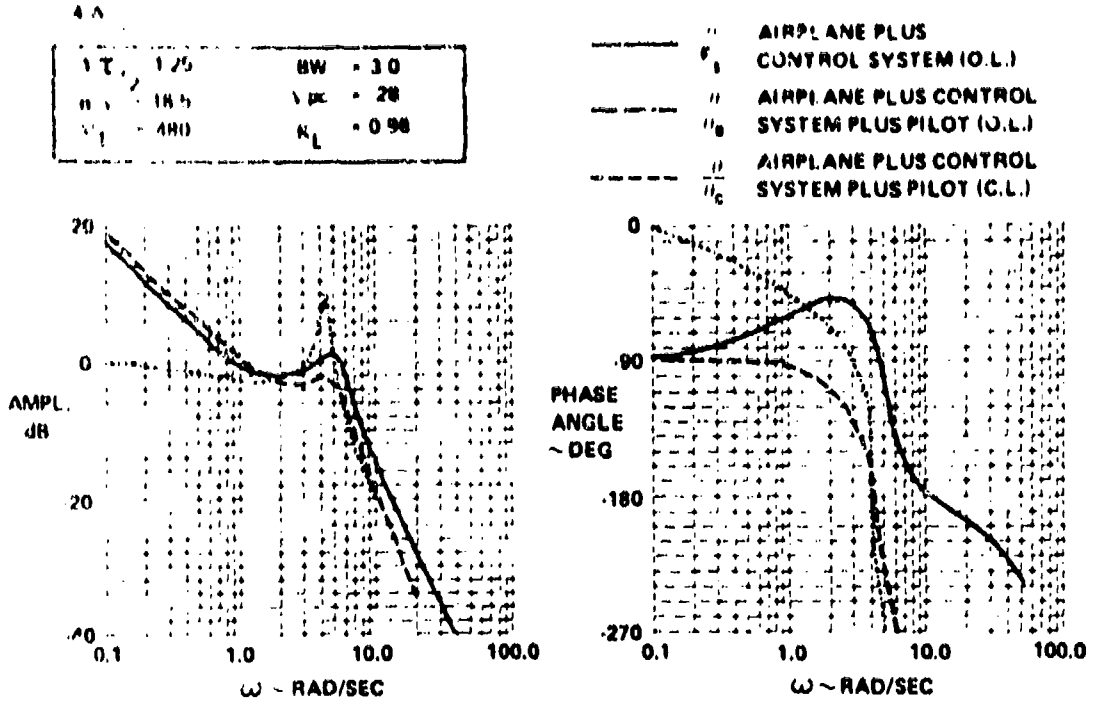
OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



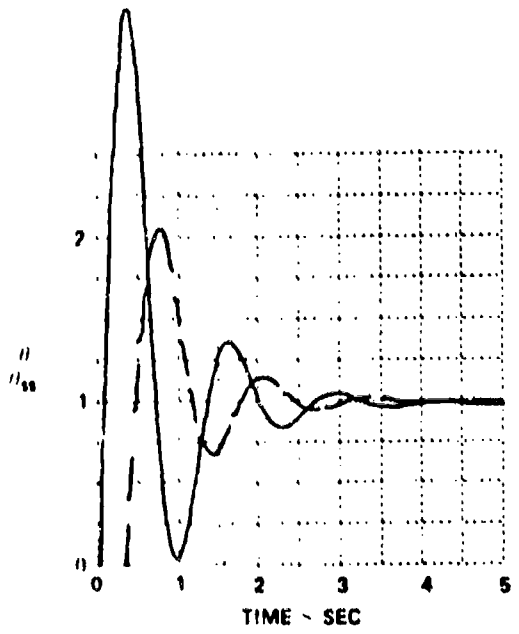
CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

4 A	CONFIGURATION [illegible]

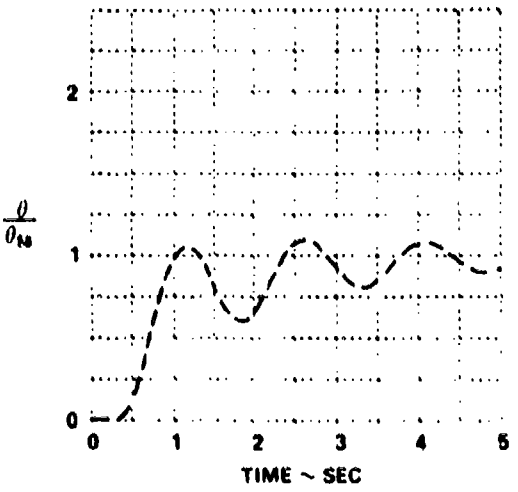
PLT/PILOT	1037 M	104 W
PR/PION	55 25	5 2
$(P_0/a)/M_{fl}$	87 0 44	5 1 0 71
M_{pc}/M_{BW}	22/14	1 1 0 82
STICK FORCES	NOT TOO BAD THE TIMING TENDED TO OSCILLATE A BIT ON TARGET SO I COULD HAVE GONE TO A SLIGHTLY HEAVIER STICK FORCE GO FROM LIGHT TO HEAVY BUT NOT VERY PRONOUNCED	GOOD FOR NORMAL MANEUVERING BUT BIT TOO LIGHT FOR SMALL RAPID INPUTS
PREDICTABILITY OF RESPONSE	A PROBLEM INITIAL RESPONSE IS QUITE RAPID BUT DOES OVERSHOOT THE TARGET BE IT A GIVEN G, A PITCH ATTITUDE, OR A TARGET	INITIAL RESPONSE SNAPPY FINAL RESPONSE NOT QUITE AS GOOD TENDED TO BE A LITTLE BIT OSCILLATORY
ATTITUDE CONTROL TRACKING CAPABILITY	ALWAYS OVERSHOOT, BUT JUST ONCE WHICH MAKES IT NOT REALLY GOOD FOR TRACKING	TEND TO OVERCONTROL JERK THE AIRPLANE ALONG FOR LARGE INPUTS GET BOBBLE OR OSCILLATIONS ON TARGET CAN MAKE SMALL ATTITUDE CHANGES QUITE PRECISELY
NORMAL ACCELERATION CONTROL	TEND TO OVERSHOOT NO MAJOR PROBLEM IN THE NEGATIVE DIRECTION NOT GOOD BUT NO REAL PROBLEM EITHER	NOT AS GOOD AS DESIRED
EFFECTS OF RANDOM DISTURBANCES	HURT THIS AIRPLANE. PILOT IS NOT VERY GOOD AT CORRECTING FOR DISTURBANCES SO IT CREATES A LOT OF WORK FOR HIM	NOTICEABLE AND CAUSE A PROBLEM THE AIRPLANE SEEMS JERKY
IFR PROBLEMS	OSCILLATORY NATURE OF THIS AIRPLANE WAS A LITTLE MORE ACCENTUATED IN THE IFR TASK	NOTICE THIS ABRUPT OR JERKY RESPONSE MORE IFR D E TRACKING TASK SHOWS UP THIS BOBBLING TENDENCY IN TRACKING TASK EASIER BECAUSE IT IS SMOOTHER
GOOD FEATURES	RESPONDS WELL INITIALLY, THEN OVERSHOOTS BUT IS REALLY NOT TOO BAD	MANEUVERABLE GOOD G CAPABILITY CAN FLY AGGRESSIVELY
OBJECTIONABLE FEATURES	OSCILLATES ON TARGET AND WHEN RAPIDLY PULLING G YOU TEND TO OVERSHOOT	BOBBLING TENDENCY WHEN STOPPING LARGE PITCH RATES WHEN GETTING ON TARGET IN HOLDING STEEP TURNS THE AIRPLANE SEEMS VERY JERKY



FREQUENCY RESPONSE CHARACTERISTICS



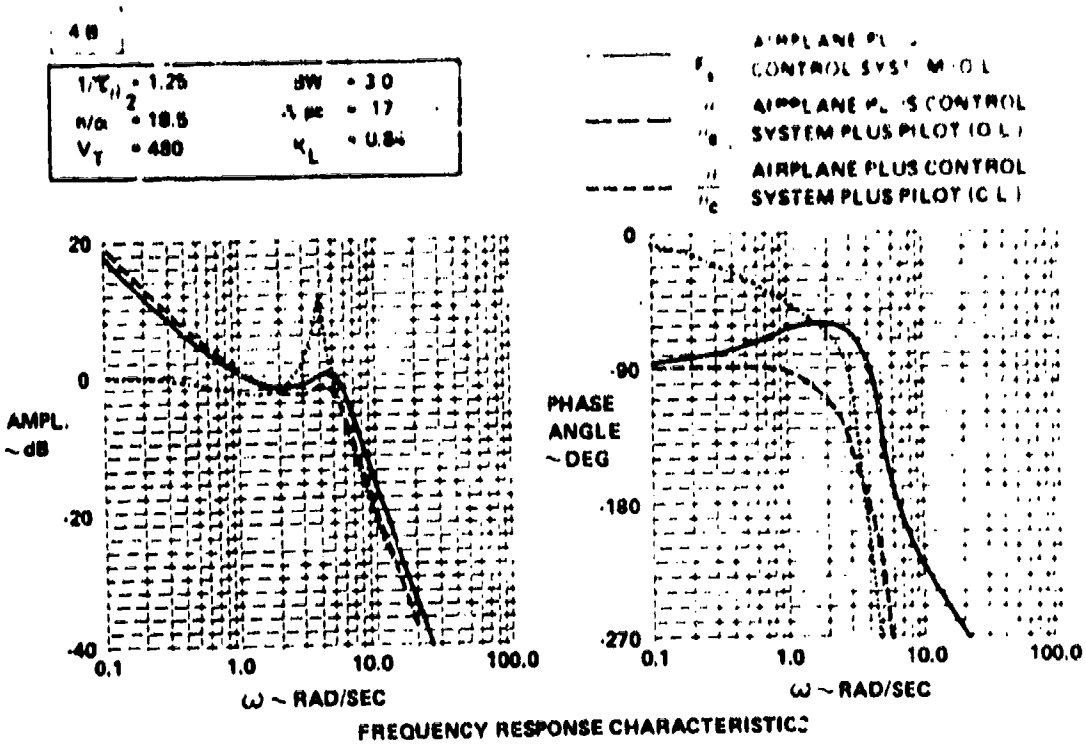
OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR δ_e IMPULSE INPUT



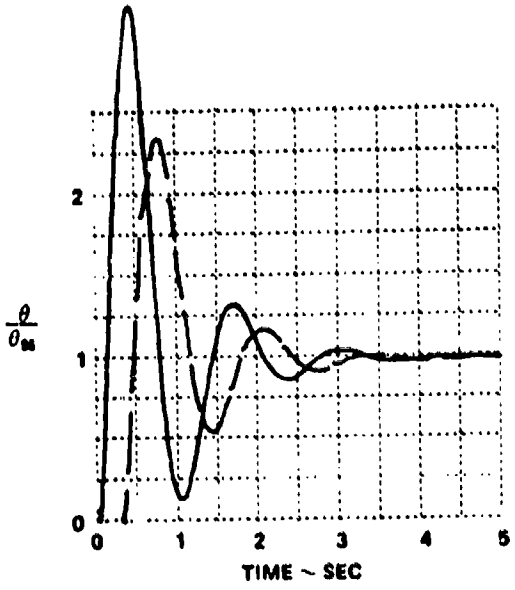
CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

4 B	CONFIGURATION ω_{BP} = 5.0 ζ_{BP} = 0.20 — /12/83

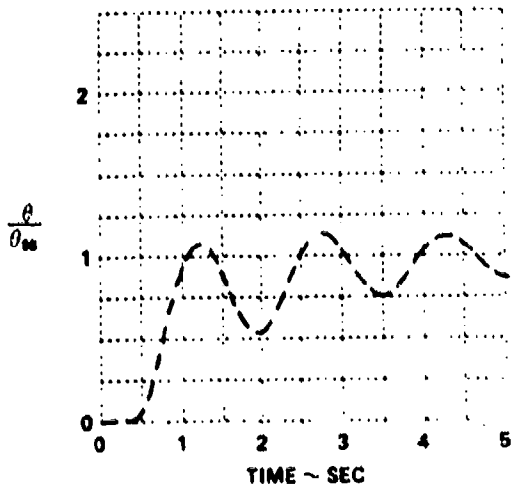
PLT /PILOT	1082/W
PR/PIOR	7/4
$(P_p/n)/K_\theta$	5.6/0.64
K_p/K_{BW}	1.2/0.92
STICK FORCES	O.K. COULDN'T GO QUITE AS LIGHT ON THE FORCES AS DESIRED BECAUSE OF TENDEN CIES TO OVERCONTROL. NO REAL SECOND THOUGHTS ON GEARING
PREDICTABILITY OF RESPONSE	NOT VERY GOOD. FAIRLY SNAPPY INITIAL RESPONSE BUT SEEMED TO BE A VERY SLIGHT INITIAL HESITATION BUT WORST PART WAS AN OSCILLATORY FINAL RE SPONSE. A LIGHTLY DAMPED PIO
ATTITUDE CONTROL/ TRACKING CAPABILITY	VERY, VERY POOR. SOME TECHNIQUES HELP TRACKING MORE THAN OTHERS BUT DON'T THINK TRACKING PERFORMANCE IS ADEQUATE FOR MISSION
NORMAL ACCELERATION CONTROL	NOT TOO BAD FOR SMOOTH INPUTS BUT OSCILLATES IN G QUITE SEVERELY IF YOU PULL G AGGRESSIVELY
EFFECTS OF RANDOM DISTURBANCES	TENDENCY TO OSCILLATE IN STEEP TURNS (VFR)
IFR PROBLEMS	STEEP TURNS WITH RN DISTURBANCES CAUSED PIO'S D. E. TRACKING WAS VERY, VERY POOR. VERY OSCILLA TORY
GOOD FEATURES	GROSS MANEUVERING CAPA BILITY GOOD
OBJECTIONABLE FEATURES	SLIGHT HESITATION IN INITIAL RESPONSE. OSCILLA TIONS DURING TIGHT TRACKING. PIO'S IN LEVEL TURNS WITH RN DISTURB ANCES



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



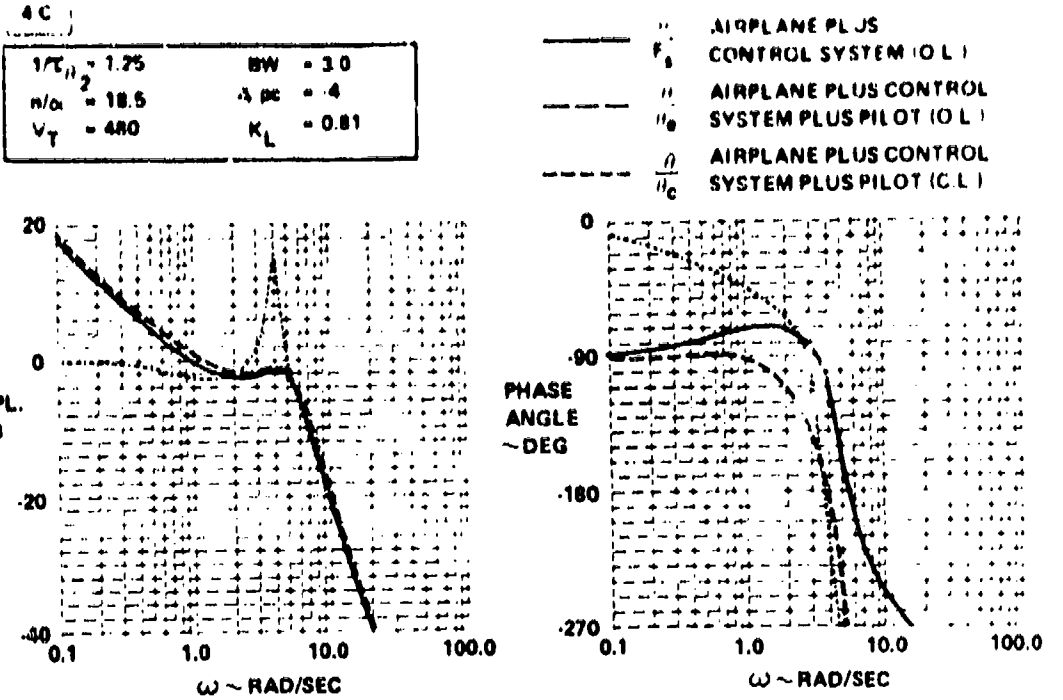
CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

4(	CONFIGURATION ω_{sp} = 3.0 ζ_{sp} = 0.70 5-6J

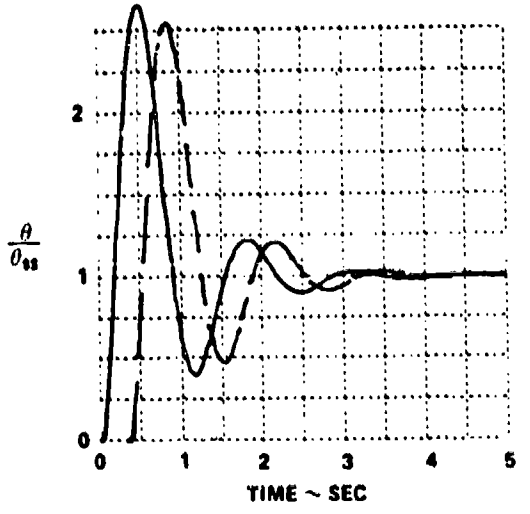
FLT/PILOT	1047/M
PR/PIOR	8.5/4
(P_s/n) K_n	3.9/0.99
K_p K_{BW}	0.82/0.76
STICK FORCES	LEANED TOWARD HEAVIER FORCES TO REDUCE PIO TENDENCY. NO SECOND THOUGHTS. GOES FROM LIGHT TO HEAVY
PREDICTABILITY OF RESPONSE	PIO PRONE SO THAT PREDICTABILITY IN TERMS OF ACHIEVING THE DESIRED ATTITUDE OR G LEVEL IS POOR
ATTITUDE CONTROL TRACKING CAPABILITY	EXTREMELY POOR. PIO PRONE
NORMAL ACCELERATION CONTROL	SAME PROBLEMS. SEEMS TO DAMP OUT QUICKER IN G THAN IT DOES ON TARGET
EFFECTS OF RANDOM DISTURBANCES	CAUSES MORE INTENSE PIO PROBLEMS
IFR PROBLEMS	VERY POOR IFR. TRACKING TASKS BOTH GET PRETTY WILD
GOOD FEATURES	NONE
OBJECTIONABLE FEATURES	PIO PROBLEMS. VERY POOR ON TARGET AND IN G PRECISION

4 C

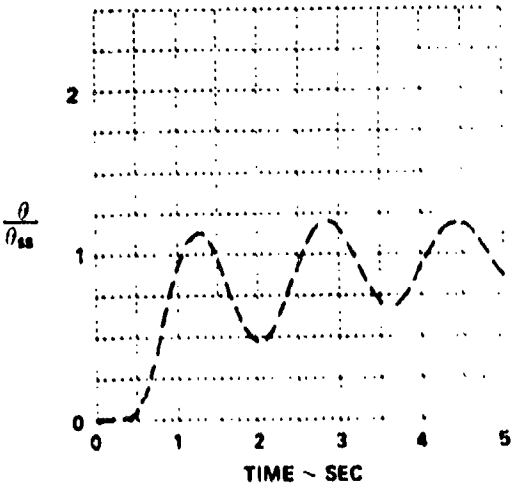
$1/T_{\theta_2}$	= 1.75	BW	= 3.0
n/α	= 18.5	Δ_{pc}	= .4
V_T	= 480	K_L	= 0.81



FREQUENCY RESPONSE CHARACTERISTICS



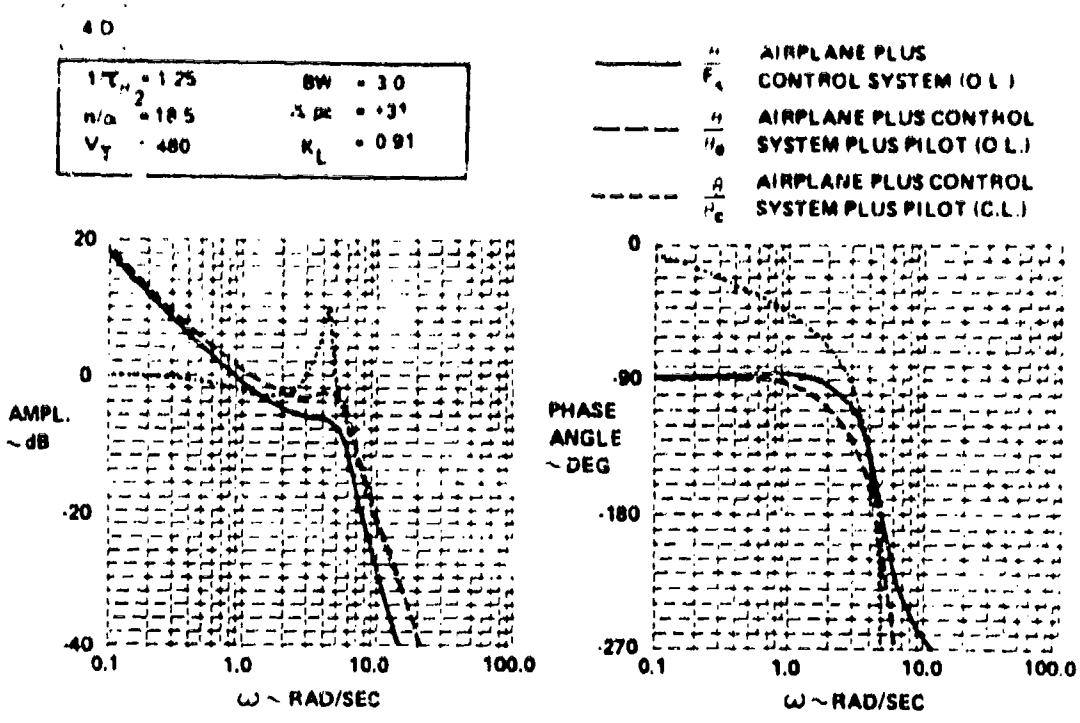
OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



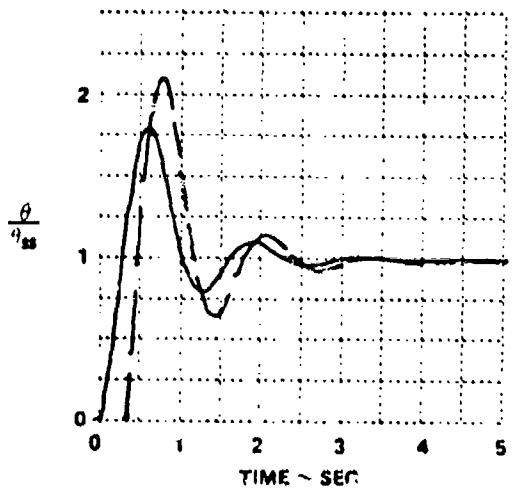
CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

4.0	CONFIGURATION ω_{sp} = 5.0 ζ_{sp} = 0.35 n/α 8.3

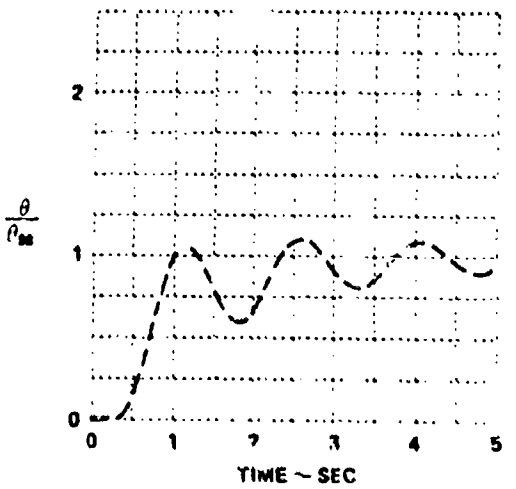
PLT PILOT	1060/M	1067 M
PR/P OR	8/3.5	9/5
$(\Phi_\phi/n)/K_\theta$	3.5/0.99	5.9/0.65
K_ϕ/K_{BW}	0.92/1.1	1.4/1.7
STICK FORCES	COULD PERHAPS HAVE GONE A LITTLE HEAVIER TO REDUCE PIO PROBLEM. INITIAL FORCES COMMENSURATE WITH STEADY FORCES	SELECTED FORCES ON THE HEAVY SIDE TO CUT DOWN ON PIO TENDENCIES. NO SECOND THOUGHTS ON GEARING SELECTION
PREDICTABILITY OF RESPONSE	NOT A PROBLEM IN THE SENSE THAT IT IS ASKED HERE. IT IS VERY PRONE TO PIO'S	VERY BAD
ATTITUDE CONTROL/ TRACKING CAPABILITY	VERY POOR. GREATLY PRONE TO PIO'S. ONCE ON TARGET IT'S RELATIVELY STEADY	EXTREMELY BAD. FULL BLOWN PIO WHENEVER YOU TRY TO AGGRESSIVELY PUT THE NOSE ON THE TARGET
NORMAL ACCELERATION CONTROL	POOR. PIO SHOWED UP IN PULLING G.	BAD, VERY BAD. OSCILLATES IN G
EFFECTS OF RANDOM DISTURBANCES	NO COMMENTS.	AIRPLANE OSCILLATES SO BADLY THAT RN DISTURBANCES ARE NOT REALLY NOTICEABLE
IFR PROBLEMS	TENDENCY TO PIO SHOWED UP CLEARLY IN DE TRACKING TASK WHEN I FLEW AIRPLANE WITH REALISTIC PILOT GAINS. HOWEVER, COULD GREATLY IMPROVE PERFORMANCE BY BACKING OFF IN GAIN.	FULL BLOWN PIO'S WHEN FLYING TRACKING TASKS AGGRESSIVELY. CAN DO TRACKING TASKS REASONABLY WELL IF YOU BACK OFF ON YOUR GAIN
GOOD FEATURES	ONCE ON TARGET IT WOULD SIT THERE.	NOT MANY.
OBJECTIONABLE FEATURES	WITH REALISTIC PILOT GAINS WOULD GET PIO'S, IN PITCH ATTITUDE AND IN G	OSCILLATES BADLY DURING TRACKING AND GROSS MANEUVERS



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

4 E	CONFIGURATION ω_{sp} = 5.0 ζ_{sp} = 0.25 -/05/6J

FLT /PILOT	1062/M
PR/PIOR	7 5/4
$(F_s/n)/K_\theta$	3.9/0 99
K_p/K_{RW}	1 9/3 5
STICK FORCES	INITIAL FORCES EXTREMELY HEAVY RELATIVE TO THE VERY LIGHT STEADY FORCES ELEVATOR GEARING WAS A COMPROMISE BETWEEN KEEPING INITIAL FORCES LIGHT ENOUGH AND AVOID ING TENDENCIES TO OVER G AND DIG IN NO REAL SECOND THOUGHTS ON GEARING SELECTION
PREDICTABILITY OF RESPONSE	EXTREMELY BAD VERY HEAVY FORCES INITIALLY, WHICH LIGHTEN DRAMATI CALLY AS RESPONSE DEVELOPS
ATTITUDE CONTROL/ TRACKING CAPABILITY	EXTREMELY POOR EX TREMELY DIFFICULT TO PUT NOSE ON TARGET OSCILLATES ON TARGET IMPOSSIBLE TO TRACK CAN GET PRETTY GOOD PIO'S GOING
NORMAL ACCELERATION CONTROL	VERY POOR BETTER THAN ATTITUDE CONTROL, BUT STILL POOR REAL TENDENCY TO DIG IN
EFFECTS OF RANDOM DISTURBANCES	A GOOD PIO RESULTED FROM ATTEMPTS TO TRACK WITH RN DISTURBANCES.
IFR PROBLEMS	TRACKING TASKS CAUSED SOME REALLY STRONG PIO'S UNLESS PILOT REDUCES HIS GAIN AN UNREASONABLE AMOUNT
GOOD FEATURES	DOESN'T REALLY HAVE ANY
OBJECTIONABLE FEATURES	EXTREMELY POOR TRACKING CAPABILITY, PIO TENDENCIES VERY HEAVY INITIAL FORCES VERY LIGHT STEADY FORCES GOOD CHANCE OF OVER STRESSING IN MANEUVERS

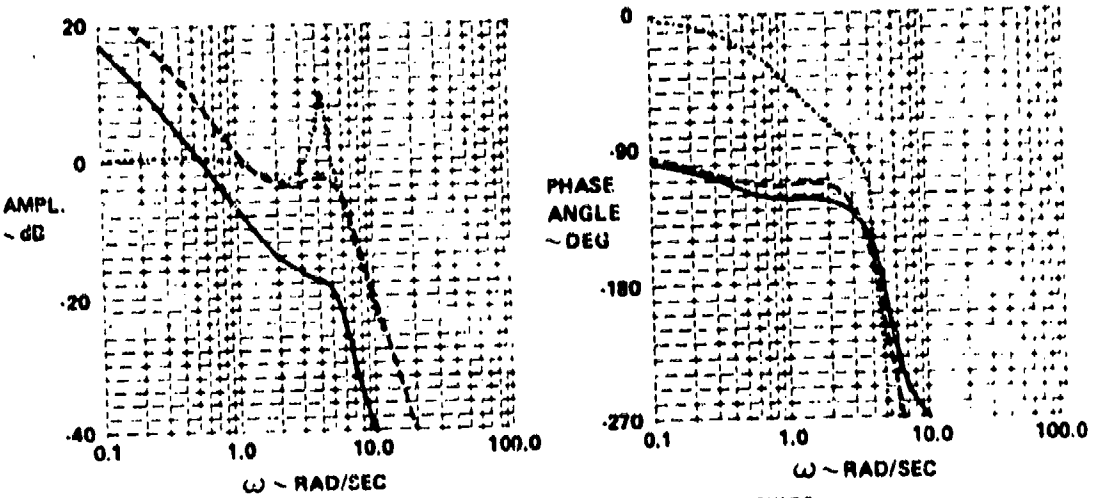
4 E

$1/\tau_{\theta_2}$	= 1.25	BW	= 3.0
n/α	= 18.5	Δ_{pc}	= +67
V_T	= 480	K_L	= 1.85

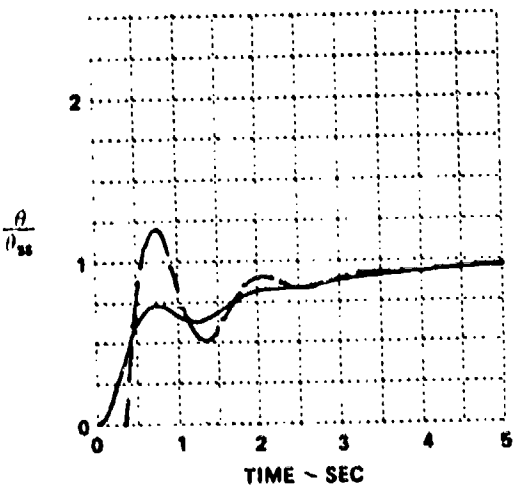
——— $\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (C.L.)

— — — $\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)

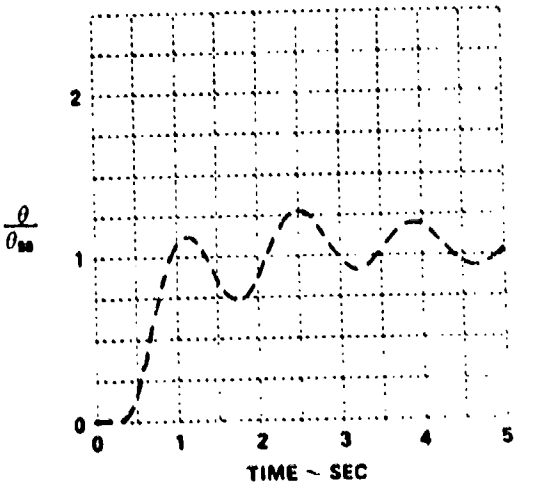
– – – – $\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

4P	CONFIGURATION ω_{sp} = 5.0 ζ_{sp} = 0.28 -/-/ 75

FLT /PILOT	1049 (1) / W
PR/PIOR	7/3.5
$(F_s/n)/K_{()}$	8.5/ 70
K_θ/K_{BW}	1.24/.87
STICK FORCES	O K SOME TENDENCY TO BOBBLE DURING GEARING SELECTION, BUT IMPROVED WITH PRACTICE SO THAT THIS TENDENCY DID NOT REALLY AFFECT THE GEARING SELECTION. SELECTED GEARING IS GOOD
PREDICTABILITY OF RESPONSE	INITIAL RESPONSE IS PRETTY GOOD MAYBE A LITTLE SNAPPY. FINAL RESPONSE HAS A LITTLE BOBBLE IN IT.
ATTITUDE CONTROL/ TRACKING CAPABILITY	IMPROVED WITH PRACTICE BUT NOT VERY GOOD. TENDS TO BOBBLE IN SETTLING DOWN ON TARGET
NORMAL ACCELERATION CONTROL	WORSE THAN ATTITUDE CONTROL. OVERSHOOTS DESIRED G AND THEN OSCILLATES SEVERAL TIMES IN SETTLING DOWN
EFFECTS OF RANDOM DISTURBANCES	EXCITES AIRPLANE A GREAT DEAL. PIO'S OCCUR JUST TRYING TO FLY STRAIGHT AND LEVEL IN THE RN DISTURBANCE.
IFR PROBLEMS	THE TRACKING TASK EMPHASIZED THE BOBBLING TENDENCIES WHICH SHOWED UP IN VFR TRACKING.
GOOD FEATURES	QUITE MANEUVERABLE SNAPPY RESPONSE
OBJECTIONABLE FEATURES	MAJOR OBJECTION IS PIO TENDENCY DURING RN DISTURBANCES. BOBBLING TENDENCY DURING TRACKING, SENSITIVE AROUND TRIM. G RESPONSE IS NOT VERY PRECISE.

NOTE (1) FLOWN WITH POSITION COMMANDS.

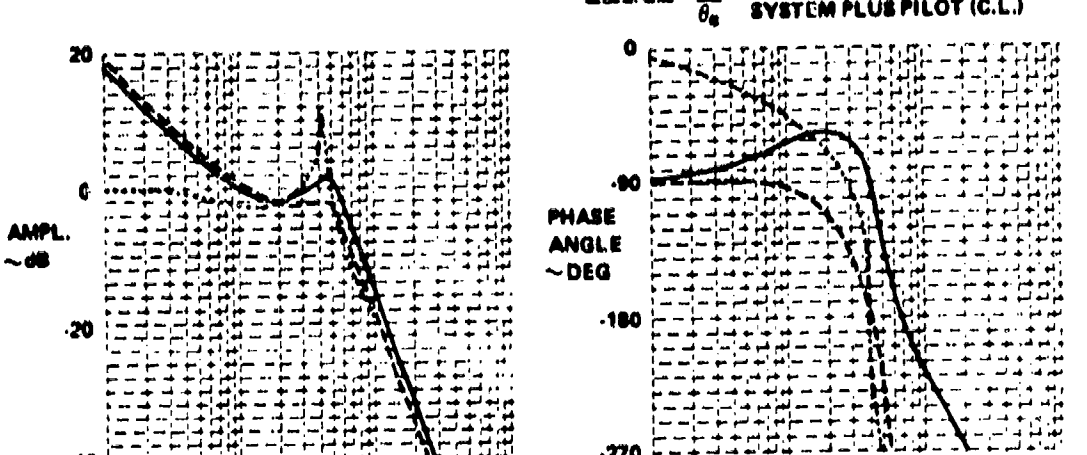
4 P

$1/\tau_{\theta_2}$ = 1.25	BW = 3.0
n/α = 18.6	ζ_{sp} = .20
V_T = 410	K_L = 0.66

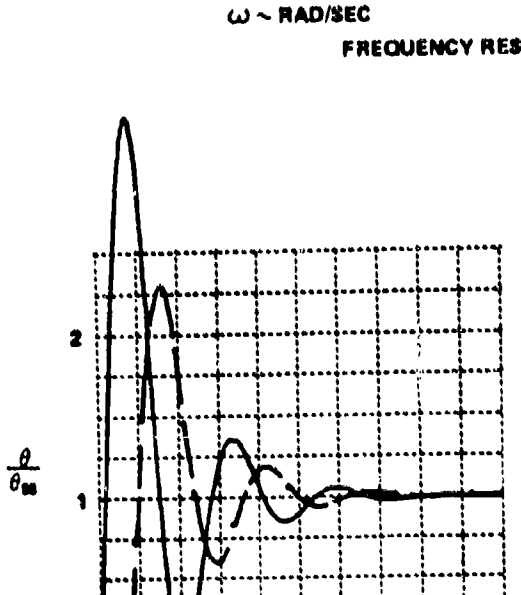
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

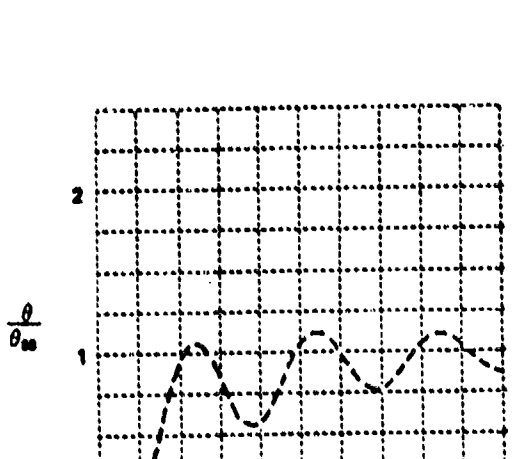
$\frac{\theta}{\theta_{es}}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



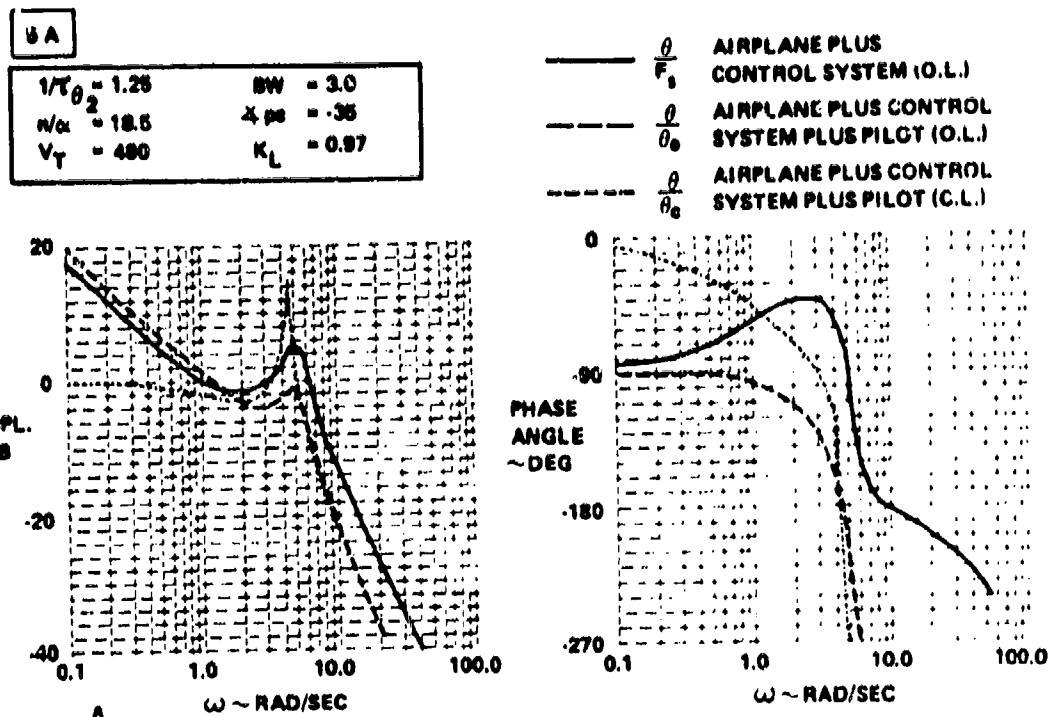
OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



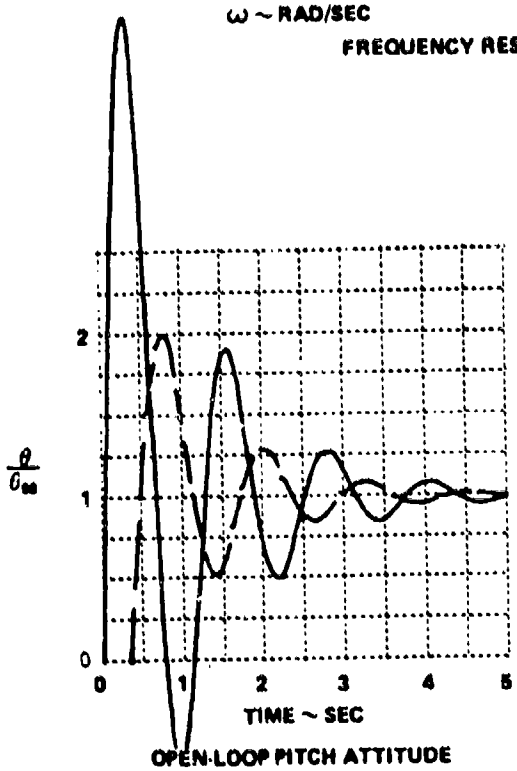
CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

5 A	CONFIGURATION ω_{sp} = 5.1 ζ_{sp} = 0.18 - / - /76

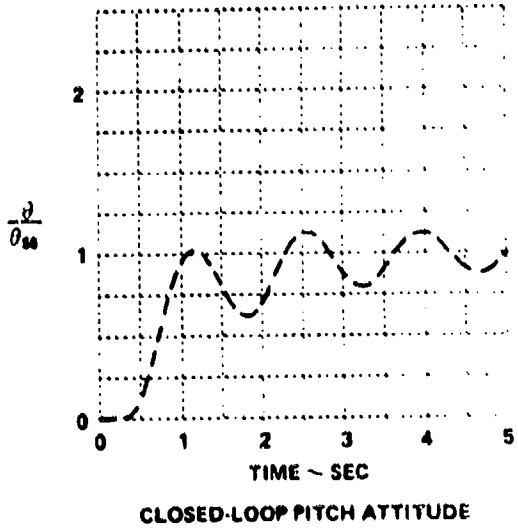
PLT /PILOT	1028/M	1028/W	1051/W
PR/PIOR	7/3	5/1 5	6/3
$(\phi_b/n)/K_{\theta}$	10 0/0 38	6 3/0 61	5 5/0.70
$K_{\phi}/K_{\phi w}$	2 5/1 3	1 3/0 86	1 4/0 74
STICK FORCES	STEADY STATE FORCES HIGH, BUT ACCEPTABLE. CHOSE THEM HEAVY TO KEEP OSCILLATORY TENDENCIES DOWN.	ACCEPTABLE, SATIS FACTORY	O K MAYBE A LITTLE ON HEAVY SIDE, BUT THIS IS O K BECAUSE IT CUTS DOWN SENSITIVITY PLEASED WITH GEARING SELECTION.
PREDICTABILITY OF RESPONSE	QUITE RESPONSIVE FINAL RESPONSE IS SOMEWHAT OSCILLATORY	NO DELAY, COMES ALONG AT RIGHT SPEED, OVER SHOOTS. INITIAL GOOD. FINAL OVERSHOOTS THEN DAMPS FASTER DAMPING CLOSED LOOP BETTER THAN OPEN LOOP LIKE INITIAL RESPONSE, FINAL COULD BE BETTER DAMPED	INITIAL RESPONSE QUITE GOOD FINAL RESPONSE NOT TOO GOOD WOULD OVER SHOOT AND OSCILLATE, BUT THEN END UP BELOW THE TARGET SOME TROUBLE PREDICTING WHERE NOSE WOULD END UP USE SMOOTH CONTROL INPUTS
ATTITUDE CONTROL TRACKING CAPABILITY	OVERSHOOTS TARGET, THEN TAKES SEVERAL SECONDS TO SETTLE DOWN ON TARGET, EVEN IN SMOOTH AIR EXCEEDINGLY DIFFICULT TO TRACK TAR GET IN TURBULENCE	FAIR, SLIGHT TENDENCY TO OVERSHOOT WHEN AC QUIRING A TARGET FOR SMALL CORRECTIONS, CAN TRACK REASONABLY WELL	NOT VERY GOOD FOR TIGHT ATTITUDE CONTROL BECAUSE OF OSCILLATIONS ON TAR GET
NORMAL ACCELERATION CONTROL	OSCILLATORY WOULD BE EASY TO OVERSTRESS	FAIR, NOT OUTSTANDING SIMILAR TO PITCH ATTITUDE CONTROL CAN SEE AN OVERSHOOT IN G BUT INCREMENTS ARE SMALL.	GOOD FOR GENERAL MANEU VERING OSCILLATORY TENDENCY WHEN TRYING TO ACCURATELY PULL G. HOW EVER THESE OSCILLATIONS ARE NOT LARGE MORE IN BOBBLING CATEGORY
EFFECTS OF RANDOM DISTURBANCES	DID NOT CAUSE NEARLY THE PROBLEMS EXPECTED, ALTHOUGH THE SMOOTH AIR PROBLEMS WERE ACCEN TUATED	ONLY BARELY NOTICEABLE THOUGHT IT WOULD BE WORSE DUE TO OBVIOUS LIGHT DAMPIN G.	NOTICEABLE EFFECT DISTURBS AIRPLANE QUITE A BIT
IFR PROBLEMS	DISCRETE ERROR TRACKING SHOWS UP OVERSHOOTING TENDENCIES SIMILAR TO VFR TRACKING	OSCILLATORY TENDENCY SHOWED UP IN DISCRETE ERROR TRACKING TASK RN TRACKING TASK SHOWED NOTHING.	EFFECTS OF RN DISTURB ANCES MORE PRONOUNCED SMALL PIO'S OCCURRED
GOOD FEATURES	RESPONSIVE	BASIC MANEUVERING IS QUITE GOOD PULLING G IS FINE RESPONSE SNAPPY BUT NOT ABRUPT	GOOD FOR GROSS MANEU VERING TRIM CHARAC TERISTICS QUITE GOOD
OBJECTIONABLE FEATURES	OSCILLATORY TENDENCY	MINOR OBJECTION IS LIGHT DAMPING WHICH SHOWS UP VERY MARKEDLY IN THE DISCRETE ERROR TRACKING	POOR TRACKING DUE TO OSCILLATORY TENDENCIES OBJECTIONABLE EFFECTS OF RN DISTURBANCES PIO TENDENCIES IFR



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

5 B	CONFIGURATION ω_{sp} = 5 1 ζ_{sp} = 0 18 – / 12 / 63

PLT./PILOT	1082/W
PR/PION	7/4
$(P_s/n)/K_\theta$	7 1/0 64
K_p/K_{BW}	1 5/1 0
STICK FORCES	O K - COMPATIBLE NO SECOND THOUGHTS ON GEARING SELECTION
PREDICTABILITY OF RESPONSE	NOT VERY GOOD INITIAL RESPONSE IS SNAPPY, BUT FINAL RESPONSE IS OSCIL LATORY AND LIGHTLY DAMPED WHEN TRYING TO SETTLE DOWN ON TARGET USE SMOOTH INPUTS
ATTITUDE CONTROL/ TRACKING CAPABILITY	POOR CAN LEARN TO DO REASONABLE JOB FOR SMALL CORRECTIONS, BUT CAN'T DO VERY WELL FOR LARGE ATTITUDE CHANGES TRACKING CAPABILITY NOT ADEQUATE FOR MISSION.
NORMAL ACCELERATION CONTROL	SOME PROBLEM CAN EASE ON THE G FAIRLY ACCU RATELY, BUT IT OSCILLATES IF YOU TRY TO ACQUIRE G AGGRESSIVELY
EFFECTS OF RANDOM DISTURBANCES	QUITE NOTICEABLE AIR PLANE OSCILLATES WHEN TRACKING IN THE PRESENCE OF RN DISTURBANCES.
IFR PROBLEMS	EFFECTS OF RN DISTURB- ANCES ARE MORE PRONOUNCED IFR THAN VFR D E TRACKING WAS QUITE POOR WITH MARKED PIO'S RN TRACKING WAS EVEN WORSE
GOOD FEATURES	GROSS MANEUVERING WITH SMOOTH INPUTS IS QUITE GOOD
OBJECTIONABLE FEATURES	LIGHTLY DAMPED OSCILLA- TIONS DURING TIGHT TRACKING CANNOT MANEU- VER AS AGGRESSIVELY AS DESIRED EFFECTS OF RN DISTURBANCES ARE OBJEC TIONABLE

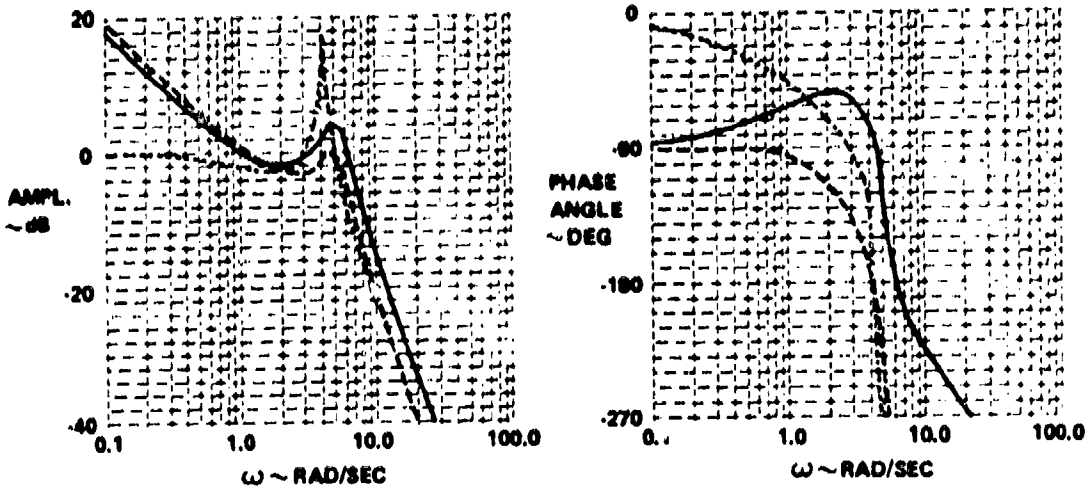
5 b

$1/T_{\theta_2}$ = 1.25	BW = 3.0
n/α = 18.5	ζ_{ps} = .25
V_T = 480	K_L = 0.81

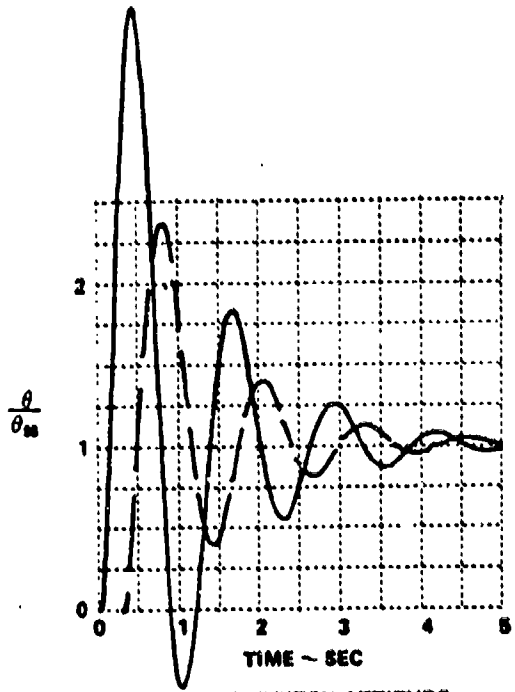
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

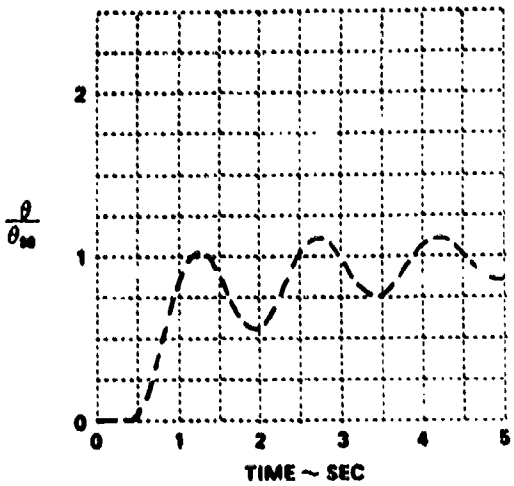
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



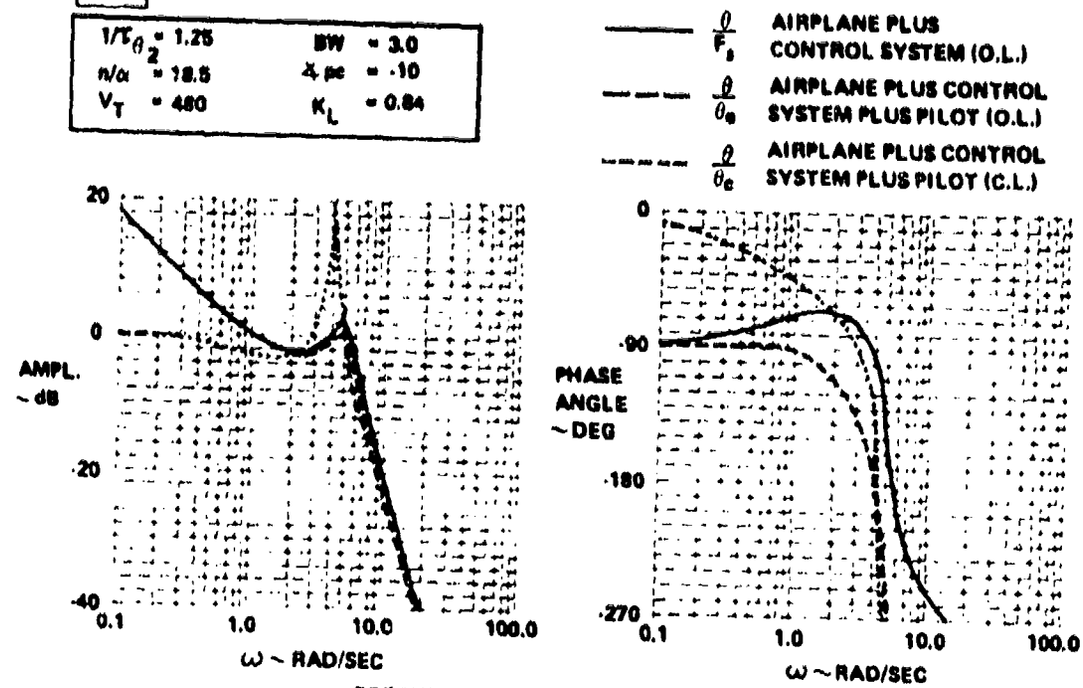
CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

SC	CONFIGURATION ω_{sp} = 5.1 ζ_{sp} = 0.18 - /5/53

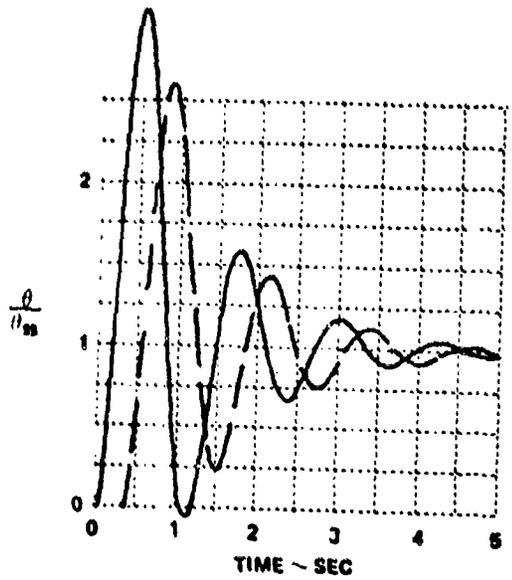
FLT /PILOT	1036/M	1056/W
PR/PIOR	5/5	7/4
$(F_s/n)/K_\theta$	7.3/0.53	7.3/0.53
K_ρ/K_{BW}	1.6/1.4	1.6/1.4
STICK FORCES	SELECTED AS HEAVY AS I COULD AND STILL PULL THE 6 G THAT IS A GROUND RULE PRIORITY GIVEN TO FIGHTER MANEUVERING REQUIREMENTS FORCES ARE LIGHT FOR SMALL INPUTS	A LITTLE HEAVY, BUT GOING TO LIGHTER FORCES PRO DUCED OSCILLATIONS IN TRACKING NO SECOND THOUGHTS ON GEARING SELECTION
PREDICTABILITY OF RESPONSE	YOU CAN PREDICT THAT IT IS GOING TO PIO	QUITE POOR INITIAL DELAY FOLLOWED BY RESPONSE DEVELOPING SMARTLY LEADS TO OVERCONTROL CAN PARTIALLY OVERCOME THIS TENDENCY BY MAKING INITIAL INPUT, THEN MOVING STICK IN OPPOSITE DIRECTION AS RESPONSE DEVELOPS THIS IS DIFFICULT FINAL RESPONSE IS OSCILLATORY MORE OSCILLATORY THE TIGHTER YOU FLY THE AIRPLANE
ATTITUDE CONTROL TRACKING CAPABILITY	VERY POOR INDEED IF YOU FLY IT LIKE AN AIRPLANE YOU GET INTO PIO'S	POOR DIFFICULT TO STOP ON TARGET AFTER ON TAR GET, IT TENDS TO PIO TECH NIQUE HELPS SOME BUT NOT MUCH.
NORMAL ACCELERATION CONTROL	SURPRISINGLY GOOD IN THE POSITIVE SENSE, BUT IN THE NEGATIVE SENSE I GO DIVERGENT	NOT VERY GOOD OVER SHOOTS DESIRED G AND OSCILLATES
EFFECTS OF RANDOM DISTURBANCES	MAKES A BAD CONFIGURA TION WORSE CAN GET INTO DEEP TROUBLE IN A BIG HURRY TO COUNTERACT THE DISTURBANCES	QUITE OSCILLATORY AND UNCOMFORTABLE DURING AN INPUTS
IFR PROBLEMS	IF YOU FLY IT LIKE A FIGHTER YOU MIGHT LOSE THE AIR PLANE IF YOU FLY IT LIKE AN OSCILLOSCOPE TYPE TASK, ON THE GROUND, CAN DO THE JOB	MANEUVERING IFR WITH AN INPUTS CAUSED OSCILLA TIONS ESPECIALLY IN TURNS D E TRACKING TASK SHOWED MARKED TENDENCIES TO OVERSHOOT AND OSCILLATE
GOOD FEATURES	FOR MODERATE MANEUVER ING THE FORCES ARE NOT TOO BAD CAN PULL POSITIVE G RELATIVELY ACCURATELY	GROSS MANEUVERING QUITE GOOD
OBJECTIONABLE FEATURES	VERY BAD TENDENCY FOR PIO'S ON TARGET GOT INTO DIVERGENT OSCILLATIONS WHEN PUSHING OVER THE TOP HEAVY STICK FORCE PER G FOR LARGE AMPLITUDE MANEUVERS	HESITATION IN INITIAL RE SPONSE TENDENCY TO OSCILLATE DURING TIGHT TRACKING EFFECTS OF AN DISTURBANCES

5 C

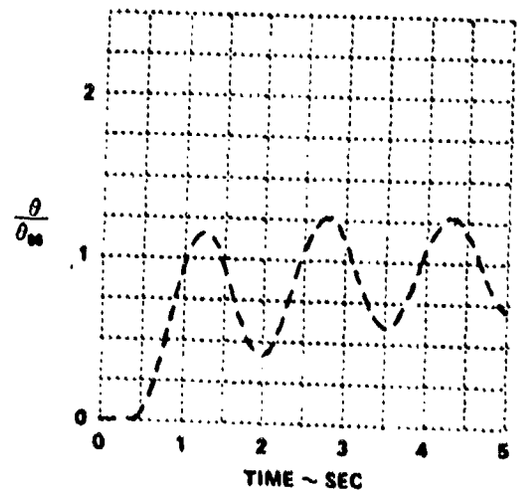
$1/\tau_{\theta_2}$ = 1.25		BW = 3.0	
n/α = 18.5		Δ_{pc} = -.10	
V_T = 480		K_L = 0.84	



FREQUENCY RESPONSE CHARACTERISTICS



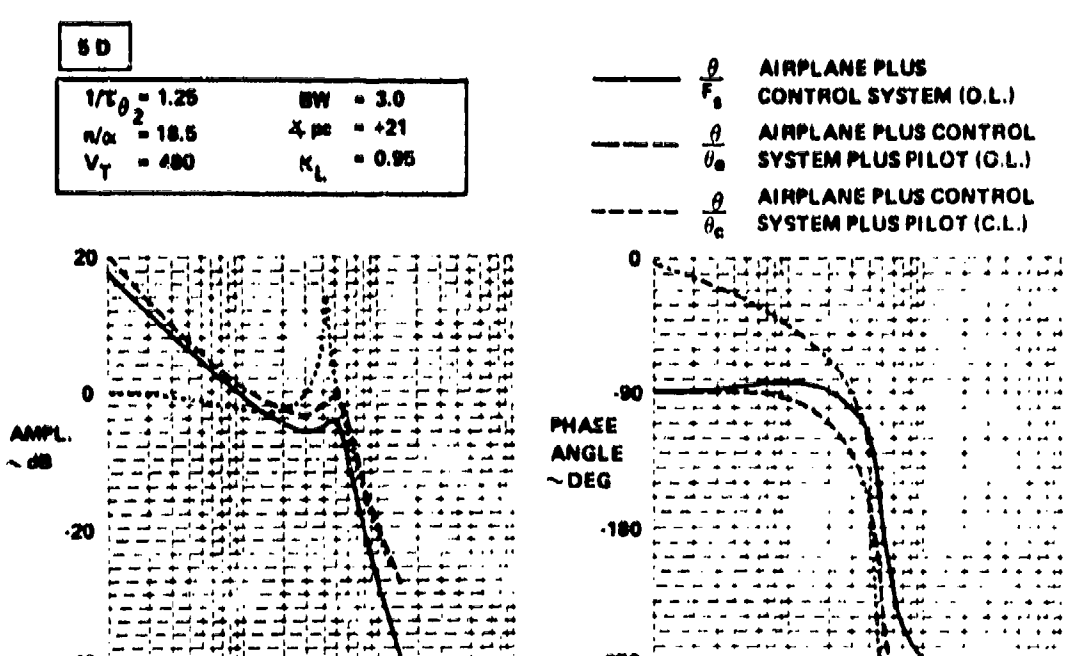
OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



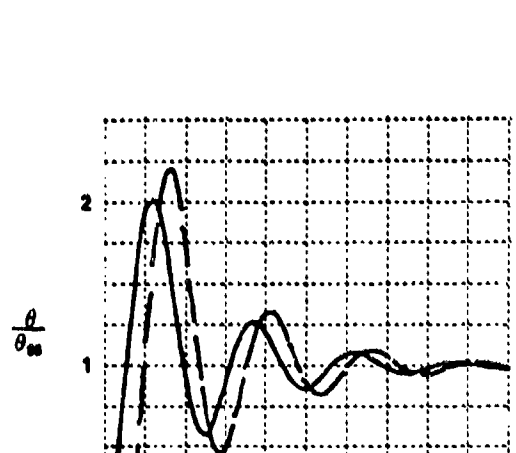
CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

5 D	CONFIGURATION ω_{sp} = 5.1 ζ_{sp} = 0.16 -/2 / 63

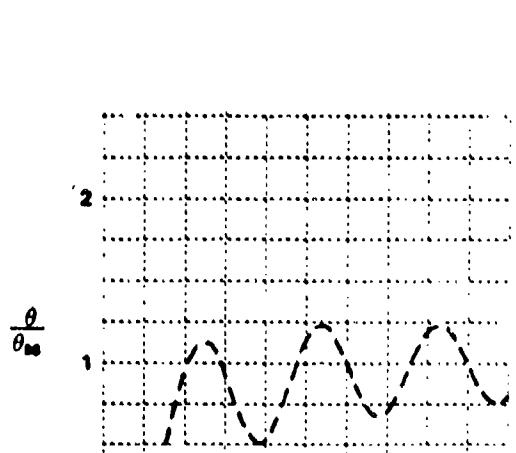
PLT./PILOT	1033/M	1067/M	1034/W
PR/PHOR	5.5/4	5/5	5/4
$(P_\phi/n)/K_\theta$	11.0/0.35	5.4/C.71	7.3/0.53
K_p/K_{BW}	2.7/2.9	1.3/1.4	1.8/1.9
STICK FORCES	COMMENTS LOST	SELECTED FORCES ON THE HEAVY SIDE TO CUT DOWN ON PIO TENDENCIES. FORCES SEEM TO BE INITIALLY HEAVY, THEN LIGHTER, AND FINALLY HEAVY AGAIN. NO SECOND THOUGHTS ON GEARING SELECTION	DESIRED LIGHTER STEADY FORCES BUT GOOD COMPROMISE
PREDICTABILITY OF RESPONSE	COMMENTS LOST	EXTREMELY POOR. GREAT DIFFICULTY IN TRACKING OR PULLING G	HARD TO PREDICT. FOR A STEP INPUT, INITIALLY NOTHING HAPPENS THEN AIRPLANE TAKES OFF. THEN HANGS UP. THEN TAKES OFF AGAIN. THIS REALLY COMPLICATES THE TRACKING PROBLEM.
ATTITUDE CONTROL/ TRACKING CAPABILITY	COMMENTS LOST	EXTREMELY POOR. PIO TENDENCIES DURING TIGHT TRACKING ARE BAD ENOUGH TO BE ON THE RAGGED EDGE OF LOSS OF CONTROL.	EXTREMELY POOR. CAN'T EVEN DO A MEDIUM TIGHT TRACKING MANEUVER WITHOUT GETTING INTO A MEDIUM FREQUENCY, ZERO DAMPED, PIO
NORMAL ACCELERATION CONTROL	COMMENTS LOST	NOT AS BAD AS ATTITUDE CONTROL, BUT STILL EXTREMELY POOR.	POOR. VERY DIFFICULT TO PULL TO AND HOLD G AND DO IT WITH ANY AGGRESSIVENESS AT ALL. CAN DO THE JOB BY EASYING UP BUT THEN THIS IS NOT A FIGHTER TASK.
EFFECTS OF RANDOM DISTURBANCES	COMMENTS LOST	AIRPLANE WAS SO LOUSY, RN DISTURBANCES WERE HARDLY NOTICED.	NOTHING SPECIFIC STANDS OUT.
IFR PROBLEMS	COMMENTS LOST	STRONG FUNCTION OF PILOT TECHNIQUE. IF FLOWN AS TIGHT AS IT MIGHT BE IN REAL LIFE, LOSS OF CONTROL FROM PIO'S IS LIKELY. CAN DO WELL IF YOU FLY THE AIRPLANE SMOOTHLY, HOWEVER.	A BIT MORE TENDENCY TO OSCILLATE IN THE NORMAL FLYING MANEUVERS D E. TRACKING TASK EXTREMELY DIFFICULT TO DO. YIELDS ALMOST A CONTINUOUS OSCILLATION. SAME FOR RN TRACKING TASK
GOOD FEATURES	COMMENTS LOST	NOT MUCH GOOD TO SAY ABOUT AIRPLANE.	CAN STOP OSCILLATIONS BY STOPPING WHAT I AM DOING WHICH IS A RATHER NEGATIVE WAY TO GET A GOOD FEATURE
OBJECTIONABLE FEATURES	COMMENTS LOST	STRONG PIO TENDENCIES DURING TIGHT TRACKING. G CONTROL IS ALSO VERY POOR BECAUSE OF OSCILLATIONS.	COULD NOT PERFORM THE FIGHTER MISSION. COULD NOT TRACK WITHOUT GETTING INTO A PIO. INITIAL DELAY AND THE HANG UP IN ATTITUDE CHANGE MADE THE FINAL RESPONSE DIFFICULT TO PREDICT



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

5.2	CONFIGURATION ω_{sp} = 0.1 ζ_{sp} = 0.18 - / 0.5 / 63

PLT./PILOT	1030/M	1041/W
PR/PIOR	8/4	8/4
$(\theta_c/n)/K_\theta$	6.3/0.61	4.4/0.7
K_p/K_{BW}	3.1/4.8	2.2/3.1
STICK FORCES	COMMENTS LOST	WIDE RANGE OF STICK FORCES, NONE OF WHICH ELIMINATED THE PIO TENDENCY.
PREDICTABILITY OF RESPONSE	COMMENTS LOST	VERY, VERY POOR CAN'T PREDICT INITIAL OR FINAL RESPONSE AS WELL AS I WOULD LIKE. INITIAL RESPONSE IS TOO SLOW. FINAL RESPONSE ALSO TOO SLOW AND OVER SHOOTS. HAD TO TRY TO ANTICIPATE RESPONSE
ATTITUDE CONTROL/ TRACKING CAPABILITY	COMMENTS LOST	BOTH PRACTICALLY NIL ANY MODERATE TRACKING GAIN SETS UP MILD BUT NEAR ZERO DAMPED PIO.
NORMAL ACCELERATION CONTROL	COMMENTS LOST	VERY POOR.
EFFECTS OF RANDOM DISTURBANCES	COMMENTS LOST	A PROBLEM IN STEEP TURNS AND IN IFR TASKS. PIO PRONE IFR WITH RN DISTURBANCES.
IFR PROBLEMS	COMMENTS LOST	WAS WORSE THAN VFR VERY PRONE TO PIO'S, PARTICULARLY IN D. E. TRACKING TASK. RN TRACK ING TASK WAS ALMOST A CONTINUOUS PIO
GOOD FEATURES	COMMENTS LOST	ONLY GOOD FEATURE WAS THAT PIO DAMPENED OUT QUICKLY IF I LET GO OF THE STICK.
OBJECTIONABLE FEATURES	COMMENTS LOST	INABILITY TO PREDICT EITHER THE INITIAL OR THE FINAL RESPONSE TENDENCY TOWARD A PIO EVEN FOR A MODERATE TRACKING MANEUVER OR NORMAL MANEUVERS, LIKE 30° BANK TURNS IN RN DISTURBANCES.

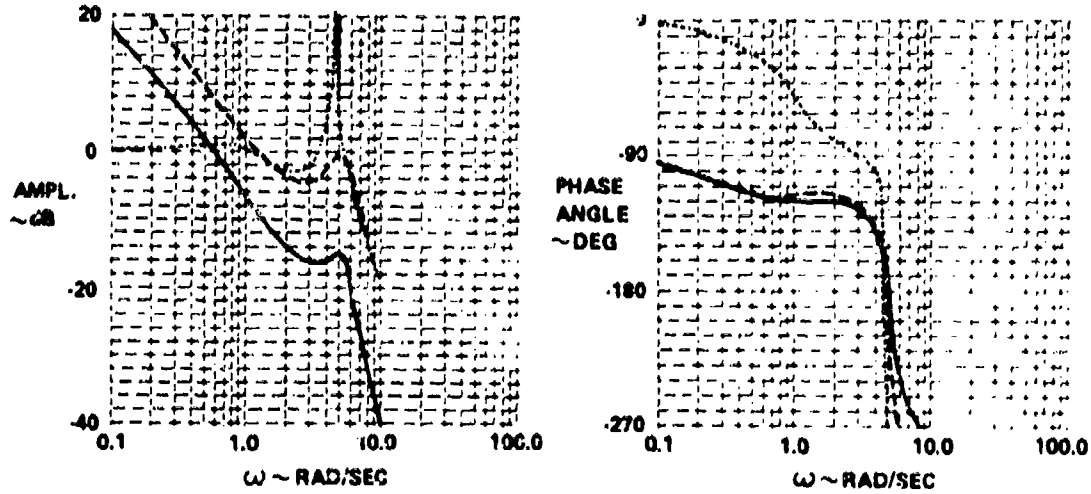
5 E

$1/T_{\theta_2}$ = 1.25	BW ~ 3.0
n/α = 18.5	Δ_{ps} = +50
V_T ~ 480	K_L = 1.89

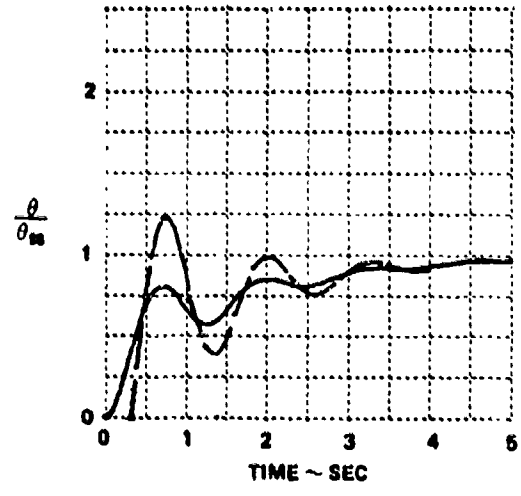
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

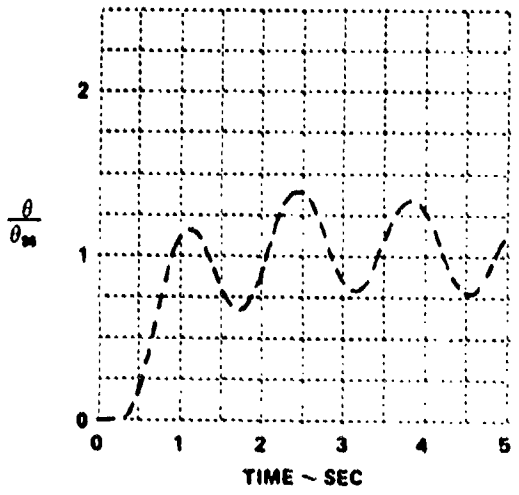
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

6 A	CONFIGURATION ω_{sp} = 3.4 ζ_{sp} = 0.87 0.8 / 3.3 / 83

PLT./PILOT	1033/M	1034/W
PR/MOR	6/2	6/3
$(\Phi_\phi/n)/K_\theta$	0.9/0.21	3.5/0.78
K_p/K_{pMN}	2.6/2.5	0.98/1.0
STICK FORCES	COMMENTS LOST	NO PROBLEM. PERHAPS COULD HAVE BEEN A LITTLE HEAVIER.
PREDICTABILITY OF RESPONSE	COMMENTS LOST	NOT REALLY VERY GOOD. FINAL RESPONSE IS PRE DICTABLE BUT INITIAL RE SPONSE IS TOO FAST OR ABRUPT
ATTITUDE CONTROL/ TRACKING CAPABILITY	COMMENTS LOST	GOOD FOR SMALL ATTITUDE CHANGES WHERE ABRUPT RE SPONSE IS NOT OBJECTIONABLE BUT FOR LARGE MANEUVER ING IT IS BAD.
NORMAL ACCELERATION CONTROL	COMMENTS LOST	ONLY FAIR; COMES ON TOO FAST.
EFFECTS OF RANDOM DISTURBANCES	COMMENTS LOST	NO COMMENTS.
IFR PROBLEMS	COMMENTS LOST	NOTHING SPECIAL TO IFR TENDENCY TO OVERCONTROL IN THE TWO TRACKING TASKS. BOTH ARE BONE CRUSHERS.
GOOD FEATURES	COMMENTS LOST	THE CAPABILITY OF MAKING SMALL ATTITUDE CHANGES FOR TRACKING.
OBJECTIONABLE FEATURES	COMMENTS LOST	ABRUPTNESS OF THE INITIAL RESPONSE. IT REALLY HURTS TO MANEUVER THE AIRPLANE AROUND.

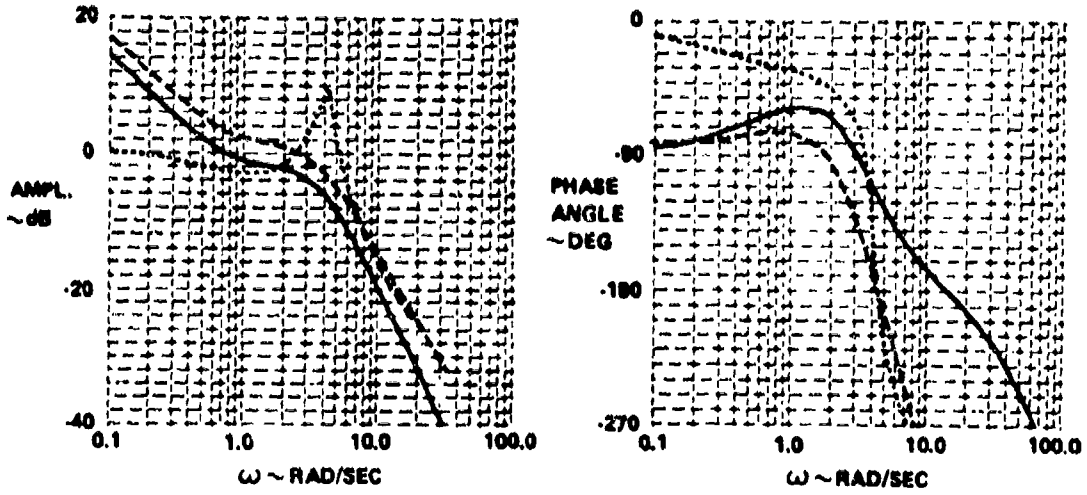
6 A

$1/\tau_{\theta_2}$ = 2.4	BW = 3.5
n/α = 50	ϕ_{BW} = +11
V_T = 675	K_L = 0.76

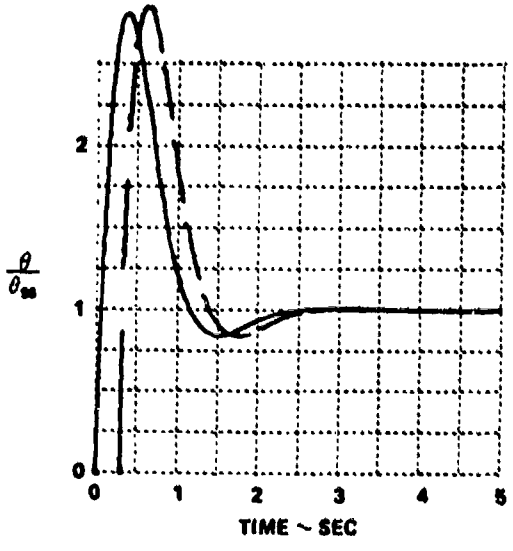
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

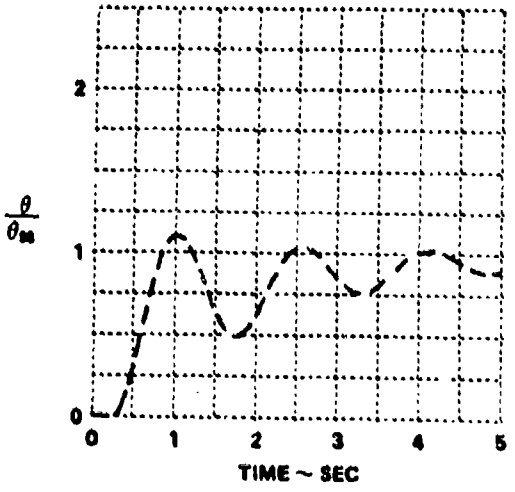
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

68	CONFIGURATION ω_{sp} = 3.4 ζ_{sp} = 0.87 3.2/8/63

PLT./PILOT	1047/M	1075/M	1074/W
PR/PICR	2.5/1.8	1/1	4/1.5
$(F_s/n)/K_\theta$	2.5/0.99	5.4/3.51	5.4/0.51
K_p/K_{BW}	1.1/1.8	2.1/2.8	2.1/2.8
STICK FORCES	VERY CLOSE TO OPTIMUM.	VERY COMFORTABLE. NO SECOND THOUGHTS ON GEARING SELECTION.	STICK FORCE LIMITED. HAD CHOSEN LIGHTER FORCES, BUT FELT HEAVIER FORCES WERE CERTAINLY COMPATIBLE WITH THE CONFIGURATION
PREDICTABILITY OF RESPONSE	GOOD.	GOOD.	QUITE PREDICTABLE. INITIAL RESPONSE A LITTLE BIT SLOW. FINAL RESPONSE SEEMED OKAY AT FIRST BUT THEN TENDED TO WANDER OFF TARGET
ATTITUDE CONTROL/ TRACKING CAPABILITY	VERY GOOD. VERY GOOD ON TARGET.	VERY GOOD. COULD VERY QUICKLY MOVE THE NOSE FROM ONE TARGET TO ANOTHER. NO WOBBLES WHEN YOU GET THERE - THE NOSE STAYS GLUED.	QUITE GOOD. ONLY PROBLEM IS TENDENCY TO WANDER OFF TARGET ONCE ESTABLISHED ON IT
NORMAL ACCELERATION CONTROL	TEND TO OVERSHOOT G JUST A LITTLE BIT; MORE PRONOUNCED IFR.	QUITE OUTSTANDING.	GOOD.
EFFECTS OF RANDOM DISTURBANCES	NO PROBLEM.	NO PROBLEM.	NOTICEABLE EFFECT. SOME DIFFICULTY COUNTERING THE DISTURBANCES.
IFR PROBLEMS	THE ABILITY TO PRECISELY CONTROL G IS NOTICEABLY LESS IFR THAN VFR.	NO PROBLEMS.	BETTER VFR THAN IFR. POOR CONTROL IN STEEP TURNS. TENDENCY TO OVERSHOOT IN D. E. TRACKING TASK BUT COULD LEARN TO AVOID PROBLEM.
GOOD FEATURES	A 3000 FIGHTER AIRPLANE. ABILITY TO ACQUIRE AND RETAIN A TARGET ARE EXCELLENT. STICK FORCES NICE AND LIGHT. G CONTROL NOT PERFECT BUT STILL PRETTY GOOD	REALLY AN OUTSTANDING AIRPLANE. VERY RESPONSIVE; WITHOUT BEING OVERLY RESPONSIVE CAN ACQUIRE A TARGET QUICKLY AND EASILY. VERY PLEASANT AND SMOOTH TO MANEUVER. FORCES WERE COMFORTABLE.	GOOD MANEUVERING AIRPLANE. EASY TO ACQUIRE A TARGET.
OBJECTIONABLE FEATURES	TENDENCY TO OVERSHOOT IN G, ESPECIALLY IFR.	CAN'T THINK OF ANY.	TENDENCY TO WANDER OFF TARGET. LARGE RESPONSE TO RANDOM DISTURBANCES. BOTH ARE MINOR OBJECTIONS.

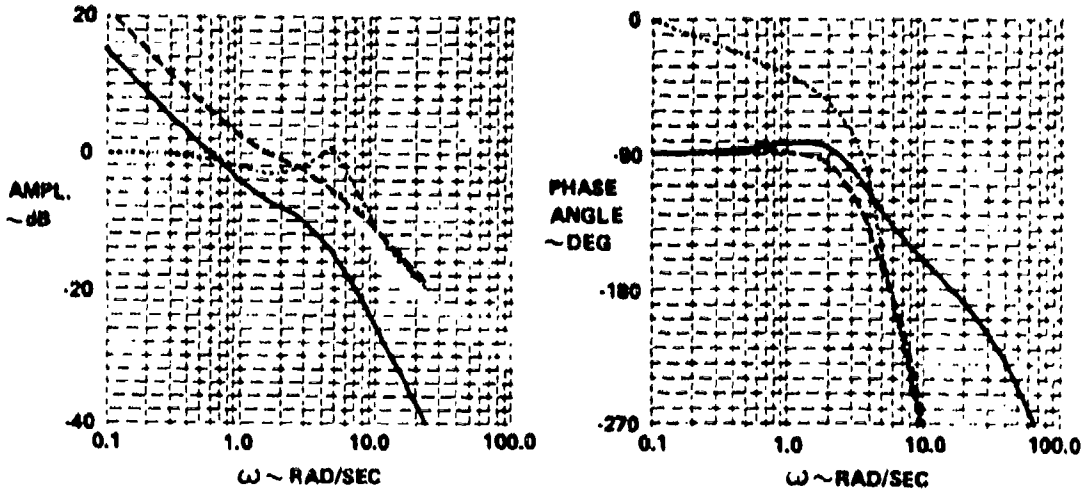
6 B

$1/T_{\theta_2}$ = 2.4	BW = 3.5
n/α = 50	ϕ_{pc} = +38
V_T = 675	K_L = 1.09

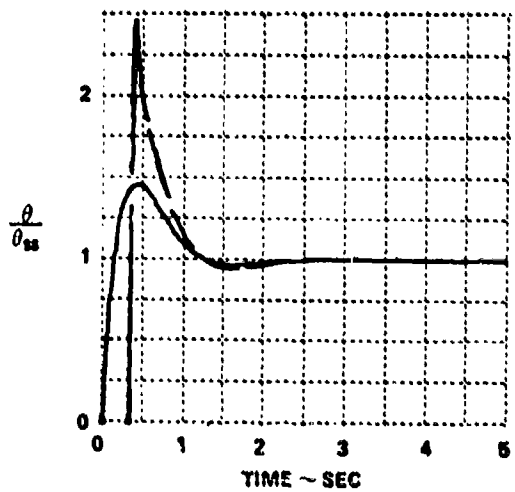
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

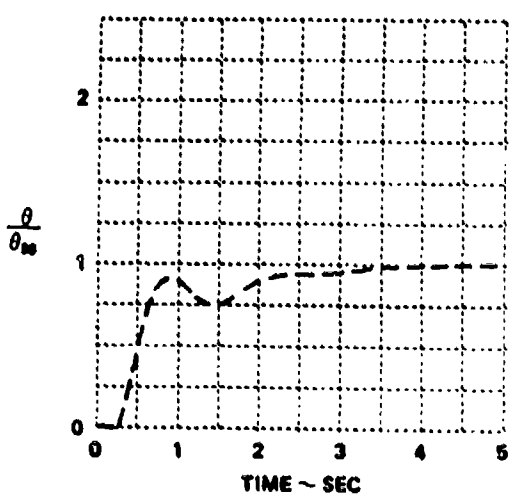
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

6C	CONFIGURATION ω_{sp} = 3.4 ζ_{sp} = 0.67 - / - / TS

PLT./PILOT	1036/M	1028*/W	1072/W
PR/PIOR	4/2.5	2.5/1	5/2
$(F_s/n)/K_\theta$	6.5/0.42	2.5/0.70	5.4/0.51
K_θ/K_{SW}	2.4/4.4	1.4/2.7	2.6/3.7
STICK FORCES	PICKED HEAVY FORCES TO AVOID DIGGING-IN TENDENCIES. AFTER LEARNING TO FLY THIS CONFIGURATION, I WOULD PROBABLY LIKE SOMEWHAT LIGHTER FORCES.	QUITE ACCEPTABLE.	QUITE GOOD.
PREDICTABILITY OF RESPONSE	DIFFICULT TO PREDICT FINAL RESPONSE FROM INITIAL RESPONSE (DIGS IN) - IMPROVED WITH PRACTICE. NEED TO OVERDRIVE SO THAT FORCES WERE INITIALLY HEAVY, THEN LIGHTER, THEN HEAVY AGAIN IN STEADY-STATE.	QUITE PREDICTABLE. INITIAL RESPONSE COULD BE A SHADE SNAPPIER BUT THAT'S VERY MINOR. FINAL RESPONSE GOOD.	NOT REALLY VERY GOOD. THE RESPONSE IS TOO SLOW. YOU HAVE TO USE PULSE LIKE INPUTS TO SPEED IT UP. THIS RESULTS IN A FAIRLY SMOOTH RESPONSE, BUT IT'S EASY TO GET MORE THAN YOU EXPECTED. WITH PRACTICE, YOU CAN LEARN TO STOP THE AIRPLANE PRETTY MUCH WHERE YOU WANT IT.
ATTITUDE CONTROL/ TRACKING CAPABILITY	PRETTY GOOD, ESPECIALLY IN SMOOTH AIR.	GOOD, VERY SOLID FEELING. NO TENDENCY TO BOBBLE GOOD TRACKING AIRPLANE.	ONLY FAIR; LEANING TOWARD THE POOR SIDE. IF YOU TONE DOWN YOUR INPUTS YOU CAN STOP NOSE WHERE YOU WANT IT REASONABLY WELL, BUT THEN YOU'RE NOT MOVING THE NOSE AS RAPIDLY AS YOU WANT.
NORMAL ACCELERATION CONTROL	DIGGING-IN TENDENCY AT FIRST - LEARNED TO PULL G FAIRLY ACCURATELY WITH PRACTICE. STILL SOME OVERCONTROL TENDENCY. MUCH WORSE DURING PUSHOVERS THAN IN PULLUPS.	GOOD, CAN PULL A VALUE OF G AND HOLD IT.	NOT GOOD. DEFINITELY OVERCONTROL WHEN YOU FLY IT AGGRESSIVELY.
EFFECTS OF RANDOM DISTURBANCES	NO NEW PROBLEMS.	NONE.	RN DISTURBANCES MOVE THE AIRPLANE AROUND QUITE A BIT, AND IT'S DIFFICULT TO GET RID OF THE EFFECTS.
IFR PROBLEMS	SEEMED BETTER IFR THAN VFR. PROBLEMS DIDN'T SEEM TO SHOW UP NEAR AS MUCH AS WITH VFR FLIGHT.	PLEASANT TO FLY.	REASONABLE AIRPLANE IFR. DIFFICULT TO KEEP UP WITH RN TRACKING TASK.
GOOD FEATURES	PRETTY STEADY ON TARGET, WHICH IS AN IMPORTANT FEATURE.	GOOD TRACKING CAPABILITY - EXCELLENT. GOOD TRIM - COMFORTABLE RIDING QUALITIES.	CAPABILITY FOR PULLING LOTS OF G IS GOOD.
OBJECTIONABLE FEATURES	DIGGING-IN TENDENCY. HAVING TO OVERDRIVE TO GET NOSE MOVING. RESPONSE CAN SURPRISE YOU IN ABRUPT MANEUVERS.	NO REAL OBJECTIONS - ONLY MINOR, BUT WOULD LIKE TO SEE SLIGHTLY FASTER INITIAL RESPONSE.	MAJOR OBJECTION IS INABILITY TO MANEUVER THE AIRPLANE SNAPPILY.

*RATINGS NOT USED IN DATA ANALYSIS - SEE DISCUSSION AT THE BEGINNING OF THIS APPENDIX.

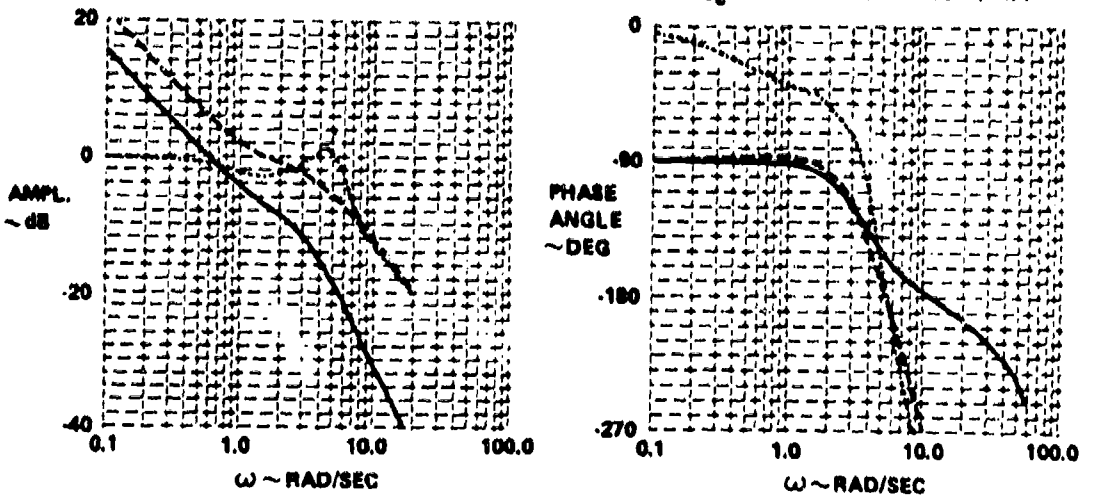
6 C

$1/T_{\theta_2}$ = 2.4		BW = 3.8	
n/α = 50		ϕ_{BW} = +67	
V_T = 675		K_L = 1.00	

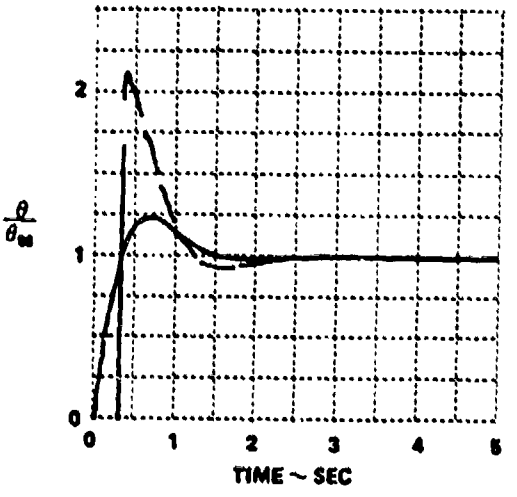
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

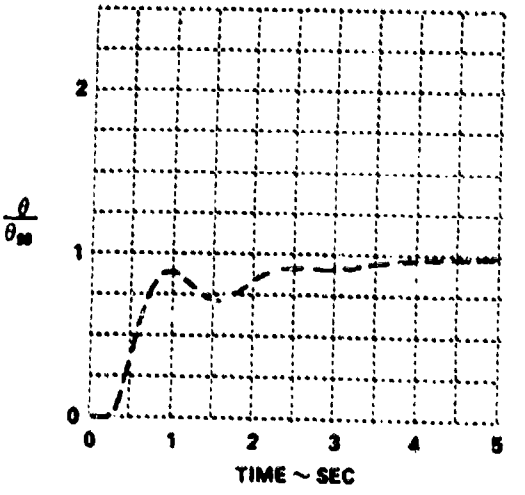
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

6 D	CONFIGURATION ω_{sp} = 3.4 ζ_{sp} = 0.67 - / 0 / 63

PLT./PILOT	1039/M
PR/PIOR	5.5/2.5
$(F_s/n)/K_\theta$	4.9/0.56
K_p/K_{SW}	1.6/4.5
STICK FORCES	LITTLE ON THE HEAVY SIDE TO PREVENT INADVERTENT INPUTS.
PREDICTABILITY OF RESPONSE	UNPREDICTABLE CAN PUT IN INADVERTENT INPUTS. PARTICULARLY BAD FOR NEGATIVE G MANEUVERS. NOT TOO BAD WHEN PULLING POSITIVE G BUT IS NON-AIR-PLANE LIKE WHICH MAKES IT DIFFICULT TO ADAPT TO.
ATTITUDE CONTROL/ TRACKING CAPABILITY	NOT REALLY VERY GOOD. HAS A TENDENCY TO PIO LARGE AMPLITUDE. ONCE ON TARGET IY IS STEADY AS A ROCK
NORMAL ACCELERATION CONTROL	PRETTY GOOD.
EFFECTS OF RANDOM DISTURBANCES	SHOWS UP A PIO YENDENCY.
IFR PROBLEMS	POINTS UP PIO TENDENCY · PARTICULARLY THE RN TRACKING TASK.
GOOD FEATURES	COULD ADAPT AND PULL G FAIRLY WELL AND MANEUVER WELL.
OBJECTIONABLE FEATURES	REALLY HAD TO COMPENSATE FOR THE DEFICIENCIES TO GET THE NOSE ON TARGET. COULD GET INTO A PIO

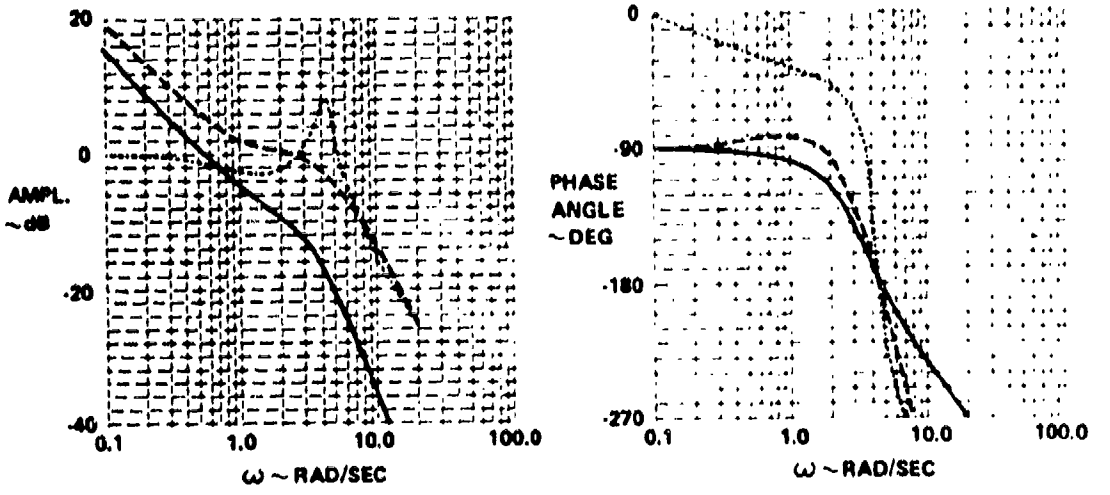
6D

$1/\tau_{\theta_2}$ = 2.4		BW = 3.5	
n/α = 50		ζ_{ps} = +67	
V_T = 676		K_L = 0.92	

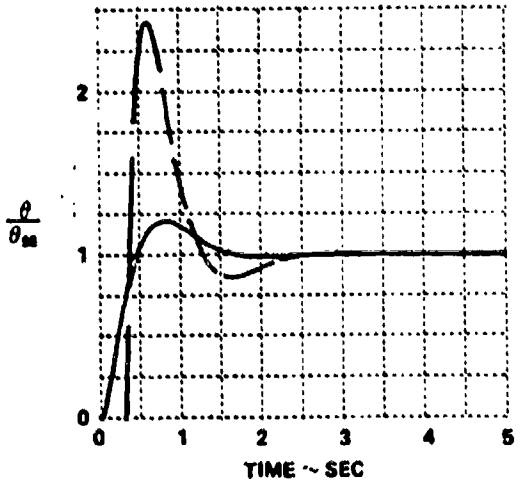
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

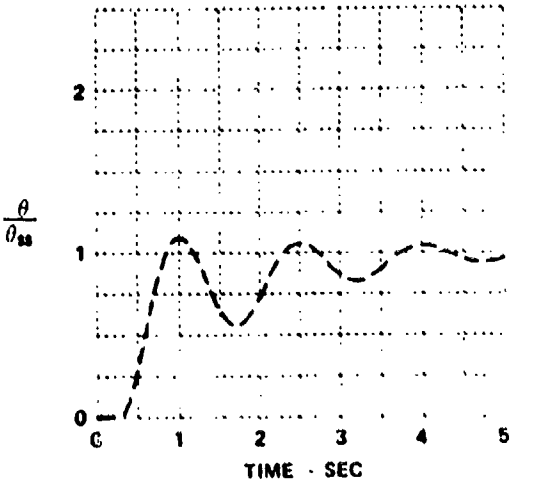
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT

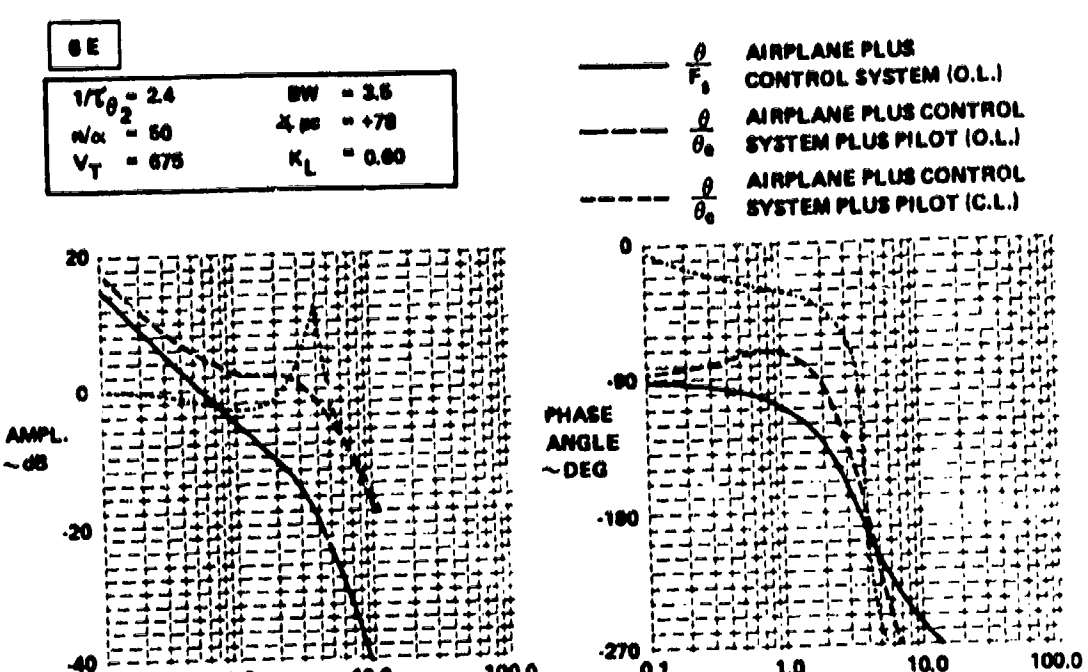


CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

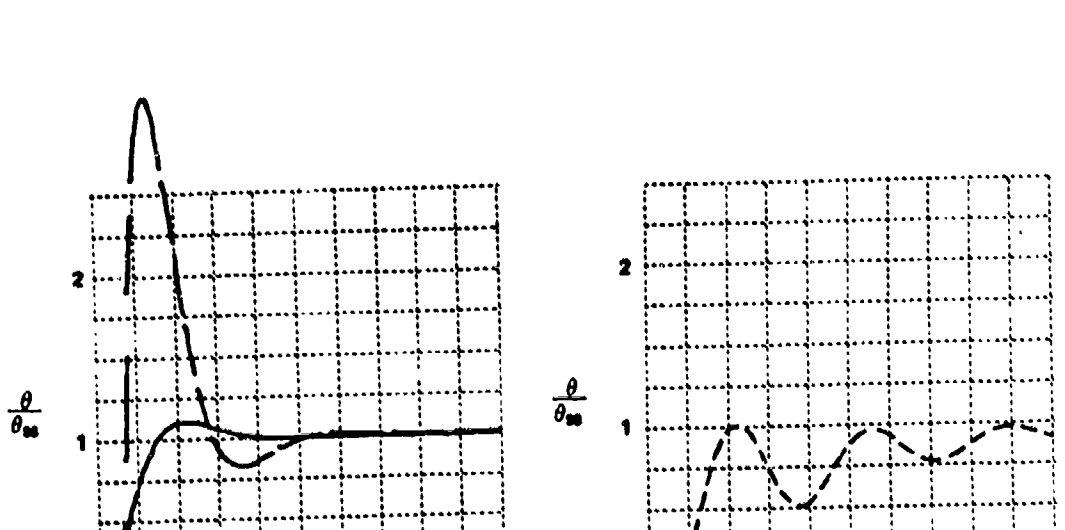
6 E	CONFIGURATION ω_{sp} = 3.4 ζ_{sp} = 0.67 -/ 3.3 / 83

FLT./PILOT	1046P/M	1071/M	1073/W
PR/PDR	5.5/2.5	8.5/5	7/4
$(\phi_a/n)/K_\phi$	3.2/0.88	5.7/0.46	5.4/0.81
K_p/K_{BW}	0.71/3.8	1.3/6.3	1.2/5.9
STICK FORCES	ON THE HEAVY SIDE TO MINIMIZE PIO TENDENCY AS MUCH AS POSSIBLE. NO SECOND THOUGHTS. INITIAL FORCES HEAVIER THAN STEADY FORCES	ON HEAVY SIDE ON PURPOSE TO HELP PREVENT UNWANTED INPUTS. NO SECOND THOUGHTS.	CERTAINLY O K. SECOND THOUGHTS - POSSIBLY LITTLE HEAVIER STICK FORCES WOULD REDUCE TENDENCY TOWARD PIO'S.
PREDICTABILITY OF RESPONSE	BEHAVES IN A PECULIAR FASHION THEREFORE NOT GOOD BUT COULD ADAPT TO SOME DEGREE.	VERY POOR INDEED. LONG DELAY IN INITIAL RESPONSE - LEADS TO PIO'S. FINAL RESPONSE NOT PREDICTABLE. KIND OF AIRPLANE THAT SCARES YOU.	INITIAL RESPONSE IS DELAYED EVEN SO SLIGHTLY. THIS LEADS TO A PROBLEM TRYING TO STOP THE AIRPLANE RESPONSE - START OSCILLATING ABOUT TARGET - GET A CLASSICAL PIO.
ATTITUDE CONTROL/ TRACKING CAPABILITY	TEND TO PIO ON TARGET A REGULAR PIO, NOT FULL BLOWN.	PIO PRONE. ON TARGET IT IS SOLID. GET LARGE AMPLITUDE OSCILLATIONS ABOUT 1 CPS.	QUITE POOR WHEN APPROACHED AGGRESSIVELY. COULD ADAPT BY USING A PULSE TECHNIQUE BUT STILL UNACCEPTABLE TO ME.
NORMAL ACCELERATION CONTROL	ABLE TO PULL G FAIRLY WELL BUT SOME OSCILLATIONS ABOUT THE G.	POOR; HAVE TROUBLE PULLING ANY CONSTANT G LEVEL.	TENDENCY TO OVERCONTROL THE G, BUT FOR GENERAL MANEUVERING IS O.K. HAVE A PROBLEM IN TIGHT TRACKING.
EFFECTS OF RANDOM DISTURBANCES	NOTHING NEW.	REALLY SCARED ME, VERY LARGE AMPLITUDE G INPUTS.	NOTICEABLE; HAVE TROUBLE COUNTERING THE EFFECTS OF THE DISTURBANCES ESPECIALLY IFR.
IFR PROBLEMS	NO NEW PROBLEM. WORKED HARD ON D. E. TRACKING TASK BUT NEVER GOT INTO ANYTHING THAT APPROACHED A FULL-BLOWN PIO.	KEPT MY GAIN DOWN BUT COULDN'T DO THE JOB. WITH NORMAL PILOT GAINS COULD GET INTO BEAUTIFUL PIO'S.	NOTHING NEW. TENDENCY TOWARD PIO IN D. E. TRACKING TASK.
GOOD FEATURES	G CAPABILITY NOT TOO BAD.	FOR GENTLE MANEUVERS AND TRACKING IT'S REALLY GREAT.	GOOD MANEUVER CHARACTERISTICS.
OBJECTIONABLE FEATURES	LIGHTENING OF FORCES AS YOU GET IN A TURN - TENDENCY TO DIG IN. TENDENCY TO PIO. RESPONSE IS NON-AIRPLANE LIKE.	ANY AGGRESSIVE TRACKING OR MANEUVERING LEADS TO PIO'S.	TENDENCY TOWARD PIO IN A TIGHT TRACKING TASK - CAN BE STOPPED BY BACKING OFF IN GAIN OR RELEASING THE STICK.

$^{\nu}$RATINGS NOT USED IN DATA ANALYSIS - SEE DISCUSSION AT THE BEGINNING OF THIS APPENDIX.



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT

CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

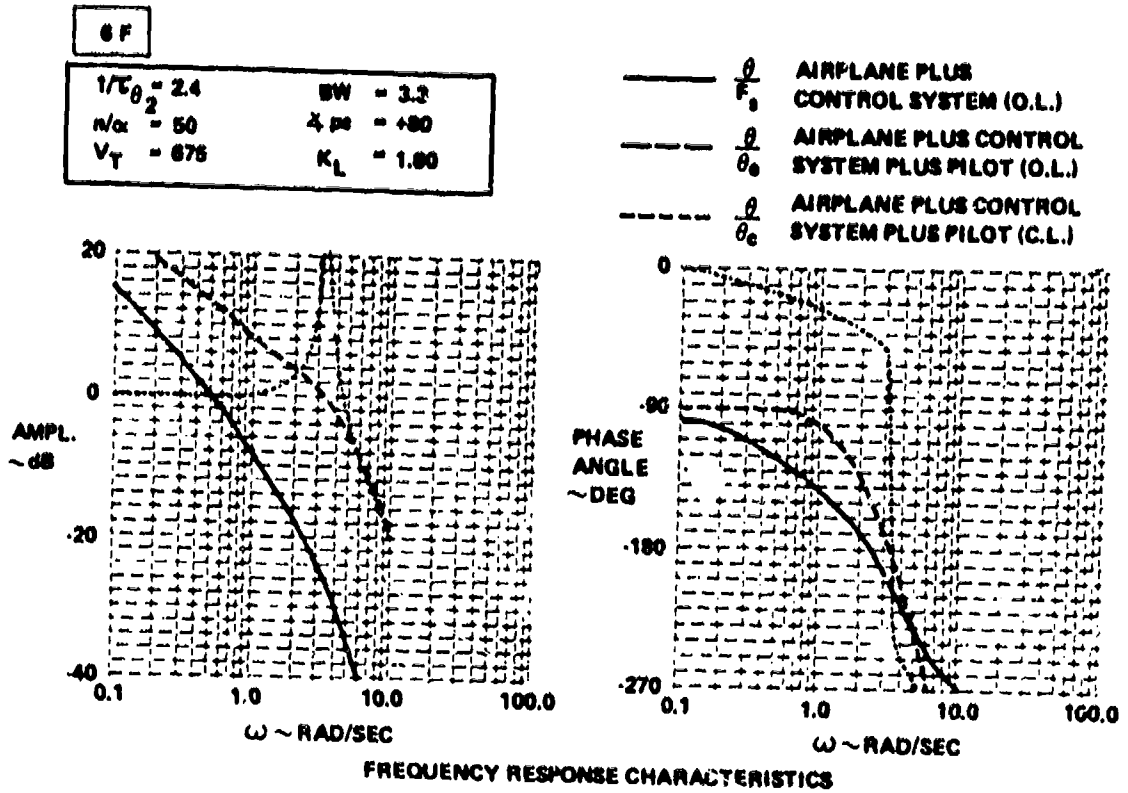
6 F	CONFIGURATION ω_{sp} = 3.4 ζ_{sp} = 0.67 -/65/68

FLT/PILOT	[illegible]	[illegible]	[illegible]	[illegible]
PE/PIGR	6/25	6/4	65/4	19/5
$(P_{\phi_{max}})_{\phi}$	7.6/0.35	8.7/0.41	3.6/0.91	5.6/0.51
$n_{z_{max}}/n_{z_{trim}}$	5.2/3.0	4.4/3.0	2.6/1.7	3.5/1.0
STICK FORCES	COMMENTS LOST	INITIAL FORCES ARE VERY HEAVY STEADY FORCES ARE LIGHT DON'T REALLY KNOW WHETHER A DIFFERENT GEARING WOULD BE BETTER OR NOT	NOT OK WOULD LIKE TO HAVE HAD LIGHTER BUT WITH LIGHTER FORCES THE OVERSHOOT IN G WAS TREMENDOUS MUST SELECT HEAVIER FORCES TO PREVENT OVERSTRESSING	TOO HEAVY FOR FIGHTER MISSION BUT LIGHTER FORCES WOULD HAVE MADE IT DANGEROUS
PREDICTABILITY OF RESPONSE	WAS BROKEN YOU HAVE TO OVERDRIVE A BIT TO GET IT MOVING BUT FELT COULD QUITE QUICKLY LEARN TO COMPENSATE FOR THIS	VERY POOR TAKES A LONG TIME FOR ANYTHING TO HAPPEN AT FIRST THEN THE RESPONSE COMES ON WITH A BANG VERY UNPREDICTABLE IN BOTH ATTITUDE AND G CONTROL	ALMOST IMPOSSIBLE INITIAL RESPONSE STARTS OUT REAL SLOW THEN TAKES OFF GIVING LARGE G OVERSHOOTS	NOT AT ALL PREDICTABLE APPRECIABLE DELAY BETWEEN THE CONTROL INPUT AND THE RESPONSE FINAL RESPONSE NOT PREDICTABLE EFFORT TO STOP RESPONSE ON TARGET LEADS TO PIO
ATTITUDE CONTROL/ TRACKING CAPABILITY	NOT THE LITTLE BOBBLE BUT THE REGULAR PIO TYPE THING	GET INTO FULL BLOWN PIO WHENEVER YOU PLY IT AGGRESSIVELY NOT VERY GOOD ON TARGET EITHER SEEMS TO WANDER	PRACTICALLY WILL GET INTO A CLASSIC PIO	FOR ALL PRACTICAL PURPOSES WILL ANY MODERATELY TIGHT TRACKING TASK SET UP A SIGNIFICANT PIO WHICH APPEARED DIVERGENT
NORMAL ACCELERATION CONTROL	COMMENTS LOST	HARD TO PULL G REALLY HAVE TO OVERDRIVE IT EASY TO OVERCONTROL	WORSE THAN ATTITUDE CONTROL UNACCEPTABLE IN A NICE STEEP TURN	POOR ATTEMPTS TO BE PRECISE LEAD TO PIO
EFFECTS OF RANDOM DISTURBANCES	COMMENTS LOST	BAD GET A PIO JUST TRYING TO HOLD NOSE ON TARGET	ATTEMPTS TO SUPPRESS RANDOM INPUTS RESULTED IN PIO	VERY LARGE RESPONSES TO RANDOM INPUTS VERY DRAMATIC EFFECTS
IFR PROBLEMS	NOTHING SPECIAL IFR	REAL TENDENCY TO PIO ON BOTH TRACKING TASKS	PIO SET UP IN ATTEMPTING TO CONTROL STEEP TURNS FLYING IFR MORE DIFFICULT THAN VFR DISCRETE ERROR TRACKING TASK NEARLY IMPOSSIBLE AND VERY UNCOMFORTABLE ON TRACKING TASK PIO'S RESULT	AIRPLANE WAS MORE MANAGEABLE IFR THAN VFR
GOOD FEATURES	PRETTY GOOD MANEUVERABILITY CAPABILITIES CAN PULL G QUITE ACCURATELY AND QUICKLY	NOT TOO BAD FOR GROSS MANEUVERING IF YOU CAN TAKE YOUR TIME AND DON'T HAVE TO FLY IT AGGRESSIVELY	NONE IN THE CONTEXT OF THE FIGHTER MISSION	TRIM
UNDESIRABLE FEATURES	MUST OVERDRIVE IT TO GET IT MOVING FORCES ARE QUITE HEAVY, SELECTED TO REDUCE PIO TENDENCY WHICH IS THE MOST SERIOUS DEFICIENCY OF THIS AIRPLANE	VERY HEAVY TO GET MOVING IF YOU TRY TO OVERDRIVE IT AS AGGRESSIVELY AS YOU WOULD HAVE TO IN A COMBAT ENVIRONMENT YOU CAN GET A PIO GOING ALWAYS AFRAID IT'S GOING TO JUMP UP AND BITE YOU VERY HARD TO GET NOSE ON TARGET NOT TOO GOOD WHEN ON TARGET	TENDENCY TOWARD OVER CONTROL OF ATTITUDE AND G PIO'S RESULT EVEN IN LEVEL TURNS IFR CAN'T TRACK AT ALL	COULD NOT MANEUVER AGGRESSIVELY WITH GETTING A WILD PIO LARGE DELAY IN INITIAL RESPONSE PIO'S WERE DIVERGENT

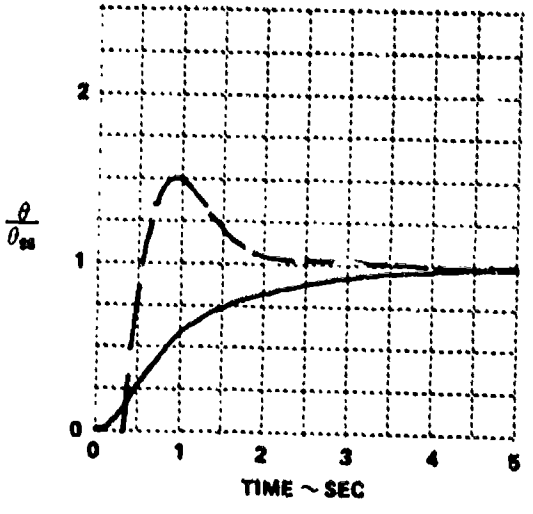
*RATINGS NOT USED IN DATA ANALYSIS SEE DISCUSSION AT THE BEGINNING OF THIS APPENDIX

6 F

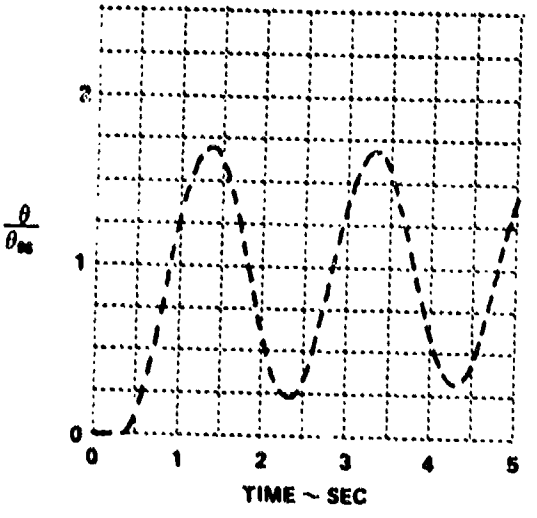
$1/\tau_{\theta_2}$	= 2.4	BW	= 3.3
n/α	= 50	$\angle_{PM}$	= +80
V_T	= 675	K_L	= 1.80



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

7 A	CONFIGURATION ω_{sp} = 7.3 ζ_{sp} = 0.73 3.3 / 0 / 63

PLT./PILOT	1046/M	1075/M	1014/M
PR/PIOR	5/2	4/2	2/1
$(P_s/n)/M_\theta$	3.7/0.74	6.2/0.44	4.7/0.58
K_p/K_{nz}	1.8/1.8	3.0/2.8	2.3/2.0
STICK FORCES	HAD TO PICK THEM VERY HEAVY TO REDUCE UNWANTED INPUTS AND COMPROMISED THE MANEUVERABILITY.	PRETTY GOOD; QUITE COMFORTABLE. SELECTED A LITTLE ON HEAVY SIDE TO KEEP SENSITIVITY DOWN. NO SECOND THOUGHTS ON GEARING SELECTION.	QUITE COMFORTABLE - NO SECOND THOUGHTS.
PREDICTABILITY OF RESPONSE	GOOD; COULD PULL A GIVEN G PRETTY WELL. INITIAL FORCES ARE QUITE LIGHT BUT HEAVY FOR MANEUVERING. VERY RESPONSIVE AIRPLANE, EASILY GET INADVERTENT INPUTS.	A LITTLE PROBLEM. TENDS TO OVERSHOOT A BIT IN ATTITUDE AND G. THE INITIAL FORCES ARE QUITE LIGHT COMPARED TO THE STEADY FORCES. THE AIRPLANE IS VERY RESPONSIVE.	INITIAL RESPONSE SNAPPY; MORE THAN NECESSARY. FINAL RESPONSE GOOD. CAN GET ON TARGET AND STAY THERE QUITE NICELY.
ATTITUDE CONTROL/ TRACKING CAPABILITY	PRETTY GOOD; COULD GET ON TARGET AND TRACK WELL.	TENDS TO OVERSHOOT IN ACQUIRING A TARGET, AND YOU HAVE TO HOLD THE NOSE ON THE TARGET FOR A SECOND TO MAKE SURE IT STAYS THERE WHEN YOU RELEASE THE FORCE. NOT REAL STEADY ON TARGET.	QUITE GOOD.
NORMAL ACCELERATION CONTROL	GOOD IN THE SENSE THAT YOU COULD PULL 3 OR 4 G QUITE ACCURATELY BUT POOR BECAUSE OF INADVERTENT G INPUTS, PARTICULARLY NEGATIVE INCREMENTS.	A BIT OF A PROBLEM. TENDS TO OVERSHOOT A LITTLE IN G.	GOOD.
EFFECTS OF RANDOM DISTURBANCES	NO PROBLEMS.	PRETTY GOOD IN PRESENCE OF RN DISTURBANCES.	NOT A FACTOR IN THE EVALUATION.
IFR PROBLEMS	NO PROBLEMS.	COULD DO IFR TASKS QUITE WELL.	NOTHING NEW.
GOOD FEATURES	RESPONSIVE.	QUITE A RESPONSIVE AIRPLANE. NICE FOR MANEUVERING. CAN CERTAINLY PULL LIMIT LOAD FACTOR. CAN MOVE FROM TARGET TO TARGET QUITE WELL.	PREDICTABILITY GOOD EVEN THOUGH IT IS A LITTLE TOO SNAPPY. MANEUVERABILITY CHARACTERISTICS AND TRACKING CAPABILITIES ARE GOOD.
OBJECTIONABLE FEATURES	STEADY-STATE FORCES TOO HEAVY. INADVERTENT G INPUTS, PARTICULARLY IN ROLL REVERSALS. TOO RESPONSIVE.	SOME OVERSHOOT IN MOVING FROM TARGET TO TARGET. INITIAL FORCES A LITTLE LIGHT. STEADY FORCES A LITTLE HEAVY. SLIGHT OVERSHOOT WHEN PULLING G.	NONE.

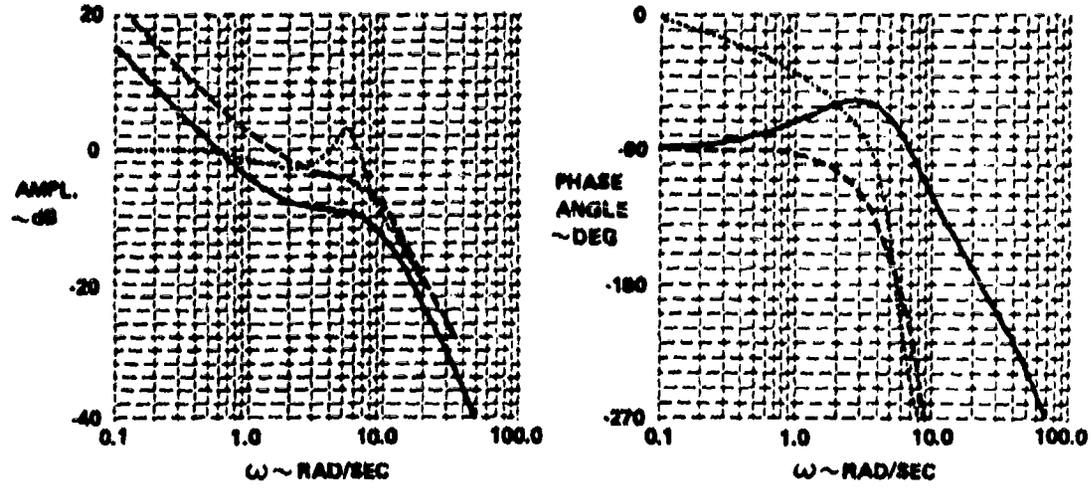
7 A

$1/T_{\theta_2}$ = 2.4		BW = 2.5	
n/α = 80		Δ_{ps} = -.16	
V_T = 675		K_L = 1.31	

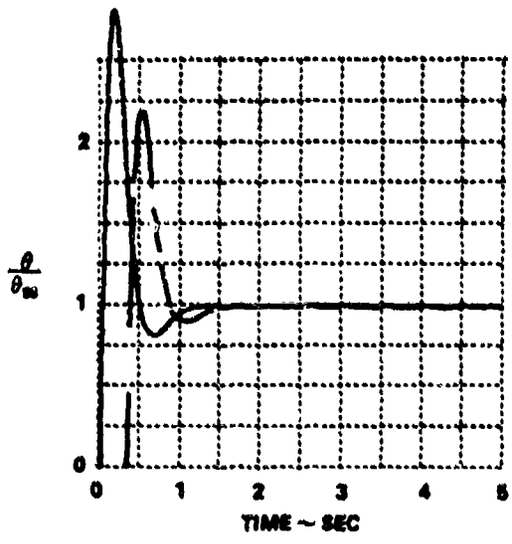
——— $\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

— — — $\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

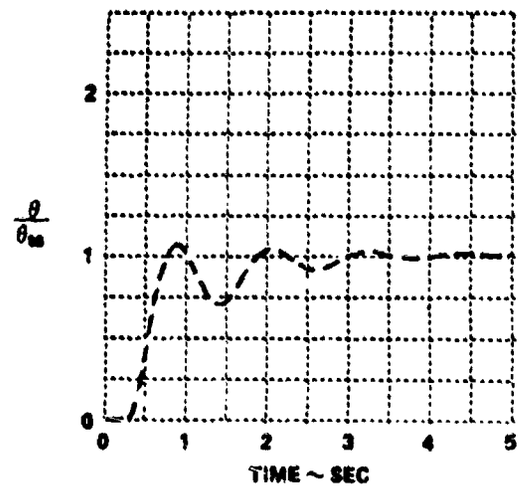
– – – – $\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

78	CONFIGURATION ω_{sp} = 1.3 ζ_{sp} = 0.73 8/19.63

FLT /PILOT	1044/M
PR/PIOR	3/1 5
$(F_s/n)/K_\theta$	3.1/0.88
$K_\phi/K_{\phi W}$	1.4/1 4
STICK FORCES	MODERATE FORCES. HAD TO PICK A COMPROMISE
PREDICTABILITY OF RESPONSE	UNPREDICTABLE IN THE NEGATIVE G DIRECTION A LITTLE BIT OF A NON AIRPLANE LIKE RESPONSE TEND TO GET UNEXPECTED RESPONSES. OVERALL IT WAS PREDICTABLE.
ATTITUDE CONTROL/ TRACKING CAPABILITY	VERY NICE IN MANY WAYS IF ANYTHING, TOO RESPON SIVE HOLD THE STICK LIGHTLY
NORMAL ACCELERATION CONTROL	GOOD. SOME OVERSHOOT BUT NOT BAD.
EFFECTS OF RANDOM DISTURBANCES	TENDENCY TO BOBBLE IN ROUGH AIR.
IFR PROBLEMS	NOTHING NEW; COULD DO A GOOD JOB.
GOOD FEATURES	SNAPPY FIGHTER MODERATE FORCES. PRETTY GOOD CON TROL OVER G AND TRACKING.
OBJECTIONABLE FEATURES	RELATIVELY MINOR LITTLE TOO RESPONSIVE TENDENCY TO PUT IN UNWANTED INPUTS. WOULD BE POOR IN ROUGH AIR

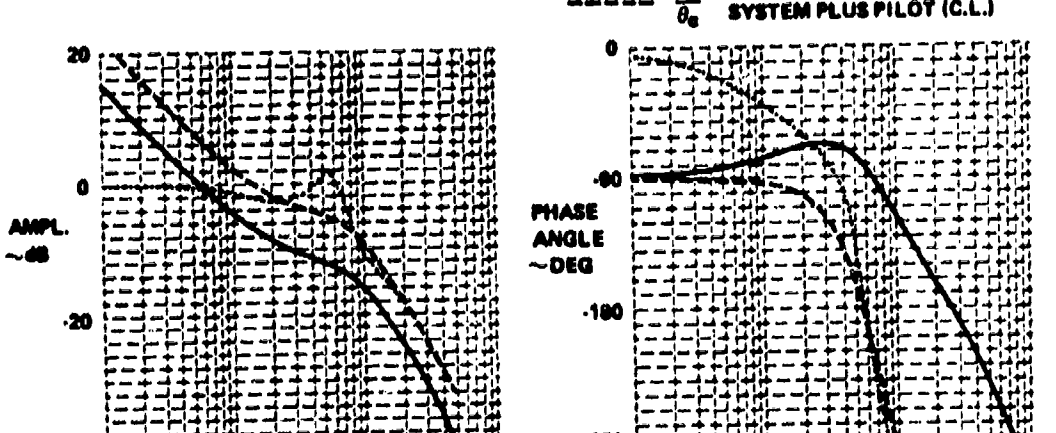
7 B

$1/\tau_{\theta_2}$	= 2.4	BW	= 3.5
n/α	= 50	Δ_{ps}	= 0
V_T	= 675	K_L	= 1.19

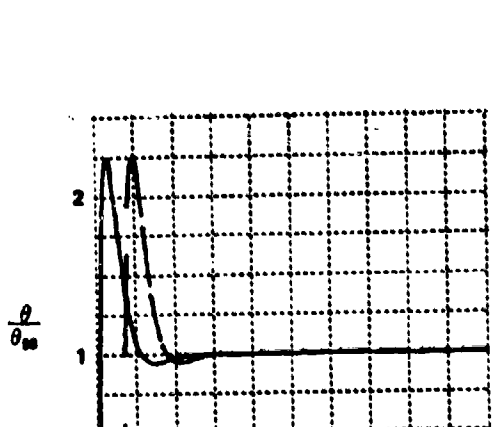
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

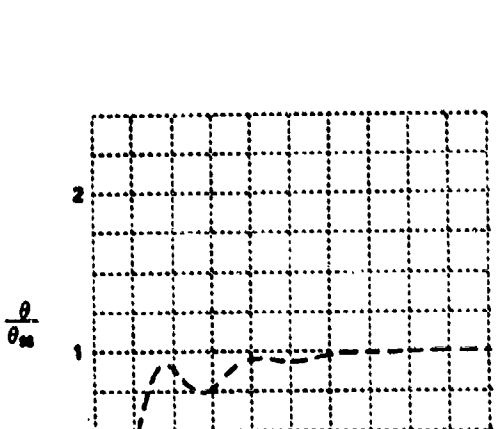
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



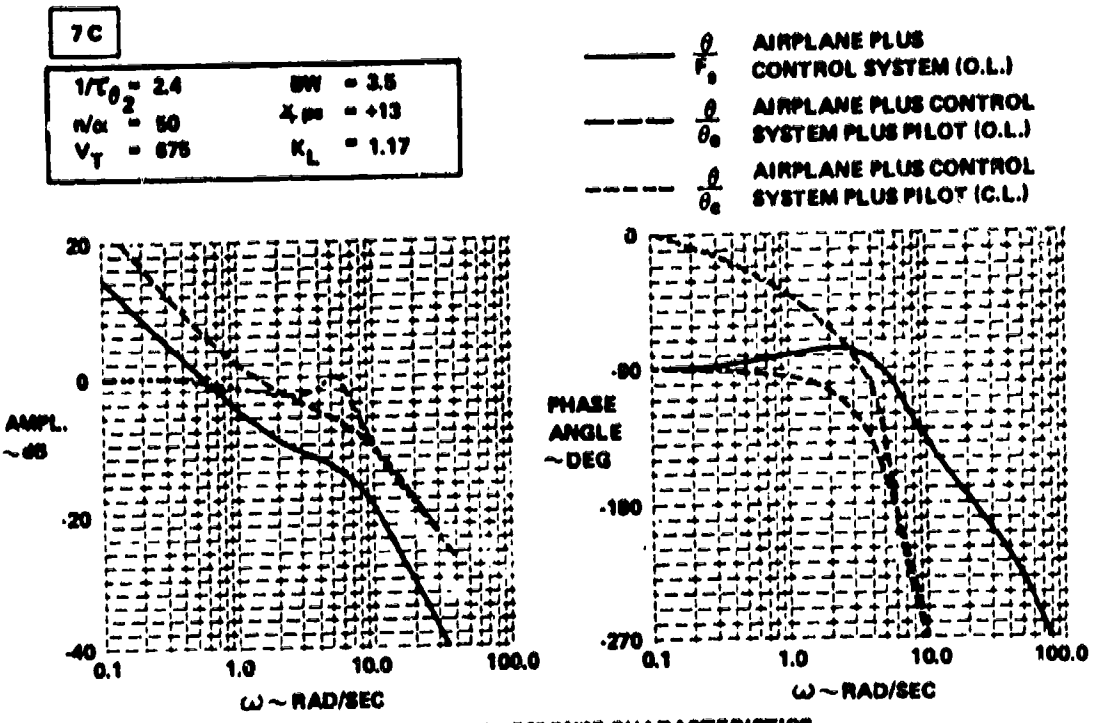
CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

7C	CONFIGURATION [illegible]

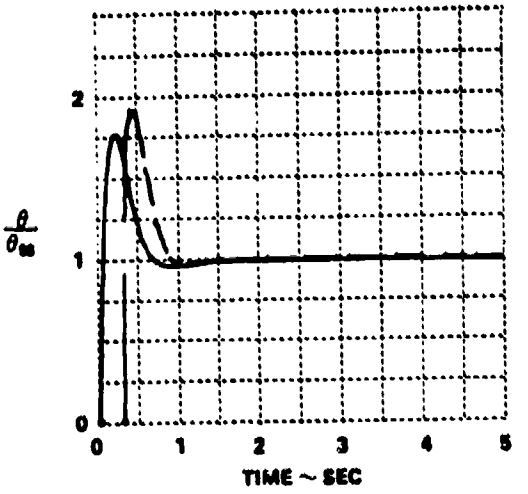
PLT./PILOT	[illegible]	[illegible]	[illegible]	[illegible]
PR/HQR	[illegible]	[illegible]	4/1	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
STICK FORCES	SLIGHT COMPROMISE BETWEEN HEAVY STEADY FORCES AND BOBBLING TENDENCIES.	GEARING SELECTION WAS A BIT OF A COMPROMISE WANTED TO KEEP FORCES HEAVY ENOUGH FOR GOOD TRACKING CAPABILITY WITHOUT MAKING STEADY FORCES TOO HIGH. NO SECOND THOUGHTS ON GEARING SELECTION	PRETTY GOOD. GEARING SELECTED A BIT LIGHT. PERHAPS. COMFORTABLE	QUITE GOOD
PREDICTABILITY OF RESPONSE	NO SURPRISES. CAN ACCURATELY PREDICT FINAL RESPONSE FROM INITIAL FORCES AND INITIAL RESPONSE	PRETTY GOOD, BUT SOME PROBLEMS IN ATTITUDE AND G CONTROL	RESPONSE SEEMED A BIT ABRUPT AT FIRST BUT WAS RELATIVELY EASY TO GET USED TO. RESPONSE QUITE PREDICTABLE	EXCELLENT. INITIAL RESPONSE QUITE SNAPPY AND NOSE STOPS WHERE YOU WANT IT
ATTITUDE CONTROL TRACKING CAPABILITY	SLIGHT TENDENCY TO OSCILLATE ON TARGET. MORE AN ANNOYANCE THAN ANYTHING ELSE	CONSISTENTLY OVERSHOOTS TARGET, THEN DROPS DOWN AND BOBBLES ON TARGET. NOT REAL STEADY ON TARGET. TENDS TO WANDER. THESE PROBLEMS ARE NOT REALLY BAD, BUT ARE NOTICEABLE	QUITE GOOD	REAL FINE
NORMAL ACCELERATION CONTROL	EXCELLENT. SLIGHT TENDENCY TO OSCILLATE BUT IT'S VERY SMALL	GOOD. TENDENCY TO OVERSHOOT G SLIGHTLY IFR, WITH SMALL BOBBLES AROUND DESIRED G.	NOT QUITE AS GOOD AS WOULD HAVE LIKED. SOME TENDENCY TO OVERSHOOT DESIRED G	GOOD. SOME TENDENCY TO OVERCONTROL SMALL G CHANGES BUT EASY TO CORRECT
EFFECTS OF RANDOM DISTURBANCES	NO UNDESIRABLE HANDLING QUALITIES CAME TO LIGHT, WHICH HAD NOT ALREADY BEEN SEEN.	NO NEW PROBLEMS.	EMPHASIZES ABRUPTNESS OF RESPONSE QUITE A BIT	NO NEW PROBLEMS
IFR PROBLEMS	MORE PIO TENDENCIES ON TRACKING TASK THAN SHOWED UP VFR. PILOT TECHNIQUE CAN ELIMINATE TENDENCY	PROBLEMS IN G CONTROL ARE WORSE IFR THAN VFR	ABRUPTNESS OF RESPONSE IS EMPHASIZED IN CONTROLLING ATTITUDE	NO NEW PROBLEMS
GOOD FEATURES	GOOD, SNAPPY FIGHTER. CAN RAPIDLY AND QUITE PRECISELY PUT NOSE WHERE YOU WANT IT AND PULL G	GOOD MANEUVERING AIRPLANE. GOOD TRACKING AIRPLANE (NOT OUTSTANDING)	LIKED TRACKING CAPABILITY LIKED FORCES.	ATTITUDE CONTROL AND TRACKING CAPABILITY ARE EXCELLENT. YOU REALLY FEEL PART OF THE AIRPLANE
OBJECTIONABLE FEATURES	SLIGHT BOBBLE ON TARGET	SOME OVERSHOOTING AND BOBBLING TENDENCIES IN TRACKING AND G CONTROL	ABRUPTNESS OF RESPONSE	NO REAL OBJECTIONS AT ALL. NOT EVEN MINOR ONES

7C

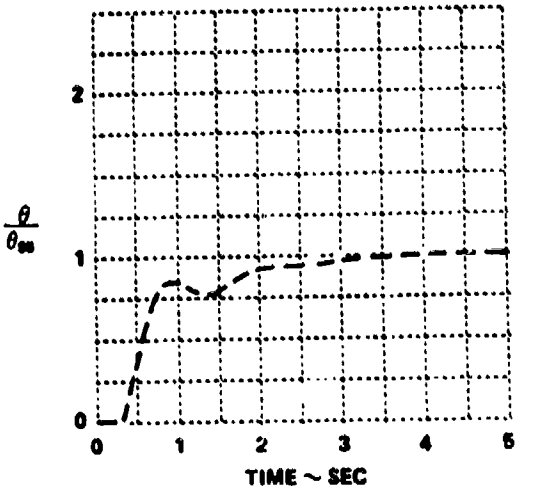
$1/\tau_{\theta_2}$	= 2.4	BW	= 3.5
n/α	= 50	χ_{ps}	= +13
V_T	= 675	K_L	= 1.17



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_e OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

7 D	CONFIGURATION ω_{sp} = 7.3 ζ_{sp} = 0.73 — / 19 / 63

FLT./PILOT	1048/M
PR/PION	8.8/3
$(F_s/n)/K_\theta$	3.0/0.81
K_p/K_{SW}	1.3/1.4
STICK FORCES	PRETTY GOOD GEARING SELECTION WAS A BIT OF A COMPROMISE BETWEEN STEADY FORCES AND TRACKING CAPABILITY
PREDICTABILITY OF RESPONSE	NOT TOO GOOD
ATTITUDE CONTROL/ TRACKING CAPABILITY	HAVE TO WORK TO ACQUIRE TARGET ALSO DIFFICULT TO HOLD ON TARGET NOT AS STEADY AS IT COULD BE SOME PIO TENDENCIES IF YOUR GAIN IS HIGH
NORMAL ACCELERATION CONTROL	SEEMED GOOD. NO REAL PROBLEMS.
EFFECTS OF RANDOM DISTURBANCES	NO PROBLEMS
IFR PROBLEMS	CLOSE TO A PIO ON THE RANDOM NOISE TRACKING TASK
GOOD FEATURES	NICE TO MANEUVER STEADY FORCES ARE A LITTLE HEAVY, BUT NOT TOO BAD
OBJECTIONABLE FEATURES	TENDENCY TO OSCILLATE ON TARGET

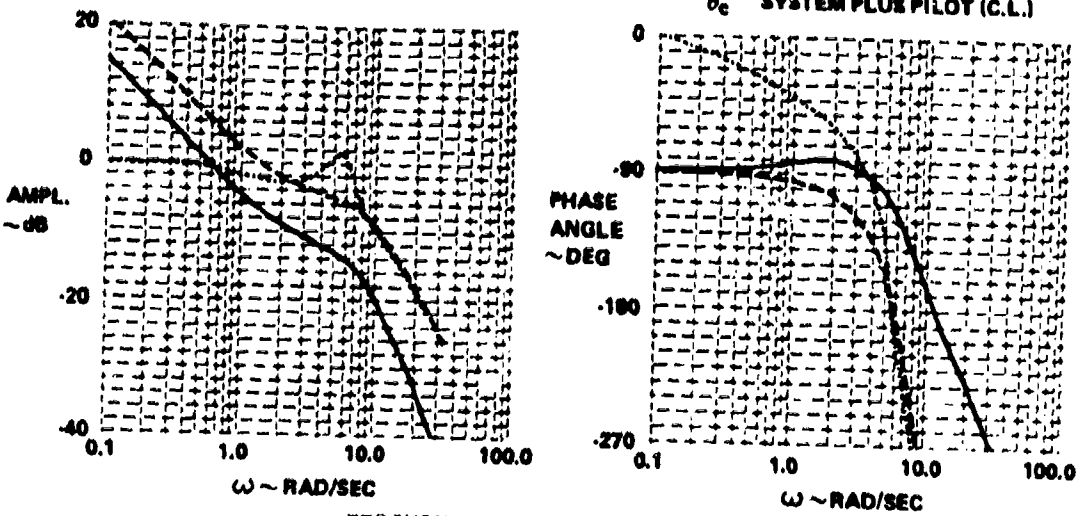
7 D

$1/\tau_{\theta_2}$ = 2.4	BW = 3.6
n/α = 50	$\angle_{pc}$ = +23
V_T = 675	K_L = 1.19

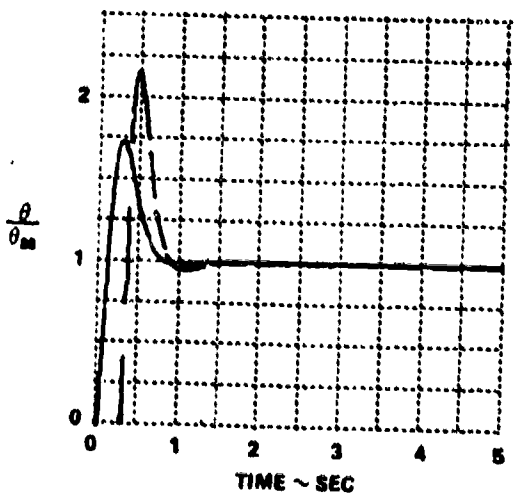
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

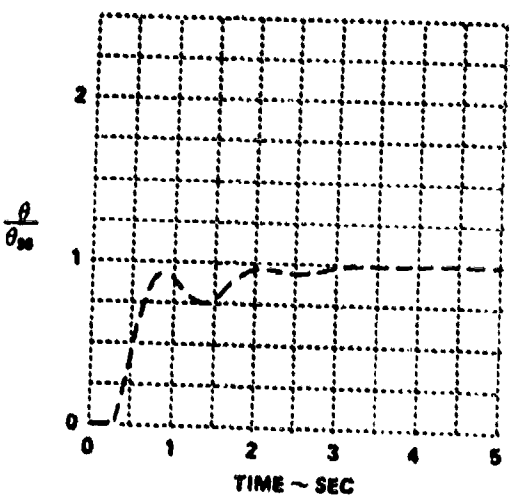
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

7 E	CONFIGURATION ω_{sp} = 7.3 ζ_{sp} = 0.73 -/0/63

PLT./PILOT	1066/M	1066/W
PR/PION	6/3	5/2
$\|P_s/n\|/K_\theta$	5.1/0.54	3.5/0.78
K_p/K_{BW}	2.2/2.8	1.5/1.8
STICK FORCES	NOT REAL HAPPY WITH FORCES. GEARING SELECTION WAS COMPROMISE BETWEEN STEADY FORCES AND TRACKING FORCES. STEADY FORCES A BIT HEAVY, BUT GEARING SEEMS TO BE AS GOOD AS ANY OTHERS TRIED	ACCEPTABLE. A LITYLE ON THE HEAVY SIDE, BUT HEAVINESS IS NECESSARY TO IMPROVE OVERCONTROL TENDENCIES
PREDICTABILITY OF RESPONSE	WASN'T VERY GOOD INITIAL FORCES WERE LIGHT STEADY FORCES HEAVIER NOT A VERY PRONOUNCED TENDENCY, BUT THE RESPONSE WAS A BIT PECULIAR	RESPONSE IS STRANGE RESPONSE STARTS OFF SLOWLY THEN PICKS UP, THEN FINALLY OVERSHOOTS, A LITTLE DIFFICULT TO LEARN TO FLY BUT NOT ALL BAD
ATTITUDE CONTROL/ TRACKING CAPABILITY	POOR OVERSHOOT TARGET, THEN SORT OF BOBBLE ON TARGET. BOBBLE ON TARGET IS PECULIAR, AND DIFFICULT TO DESCRIBE.	FAIR HAVE TO PUT INPUT IN THEN START CHECKING WITH OPPOSITE DIRECTION WORST WITH LARGE INPUTS COULD USE PULSES TO MAKE SMALL ATTITUDE CHANGES
NORMAL ACCELERATION CONTROL	NOT AS MUCH OF A PROBLEM AS WITH ATTITUDE CONTROL, BUT DOES TEND TO OVERSHOOT DESIRED G.	TENDENCY TO OVERCONTROL UNLESS MANEUVER IS DONE SMOOTHLY
EFFECTS OF RANDOM DISTURBANCES	NOTHING NEW.	NOTICEABLE, BUT NO SIGNIFICANT EFFECTS.
IFR PROBLEMS	SOME TENDENCY TOWARD PIO SHOWED UP DURING TRACKING TASKS, BUT NOT VERY PRONOUNCED.	NO NEW PROBLEMS. SOME OVERSHOOTING TENDENCIES ON THE D.E TRACKING
GOOD FEATURES	NOT TOO BAD FOR MANEUVERING. OVERALL FORCES NOT BAD.	MANEUVERABILITY AND G CAPABILITY ARE GOOD.
OBJECTIONABLE FEATURES	REAL PROBLEM IN ACQUIRING AND TRACKING A TARGET RESPONSE TO PILOT INPUTS IS PECULIAR AND UNPREDICTABLE SOME OVERSHOOTING TENDENCY IN MANEUVERING	TENDENCY TO OVER G AIRPLANE AND OVERSHOOT TARGET

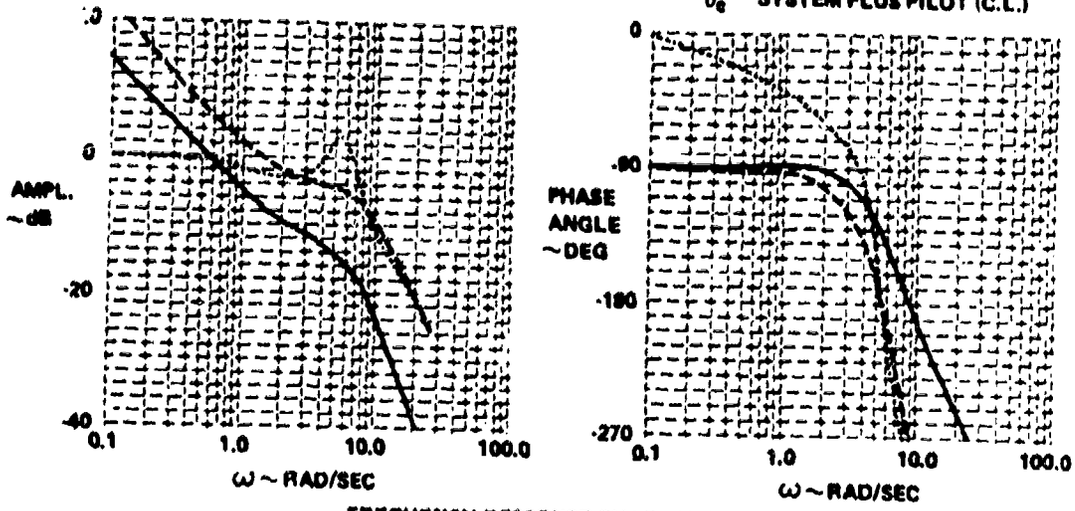
7 E

$1/T_{\theta_2}$ = 2.4	BW = 3.6
n/α = 60	ϕ_m = +38
V_T = 675	K_L = 1.19

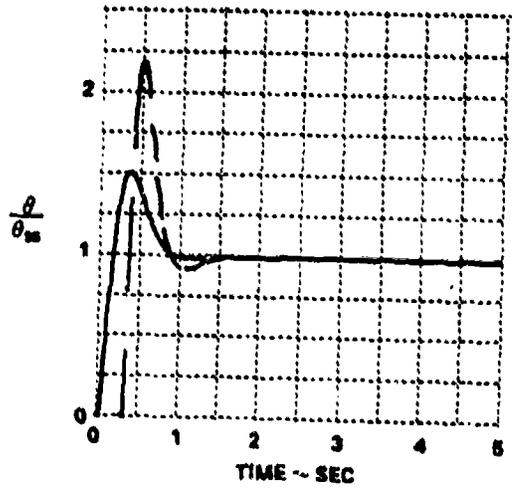
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

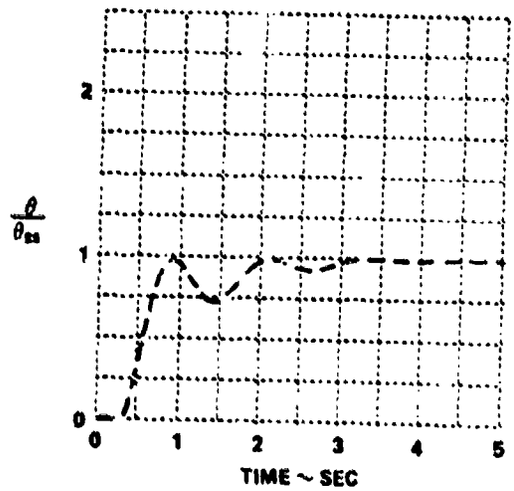
$\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

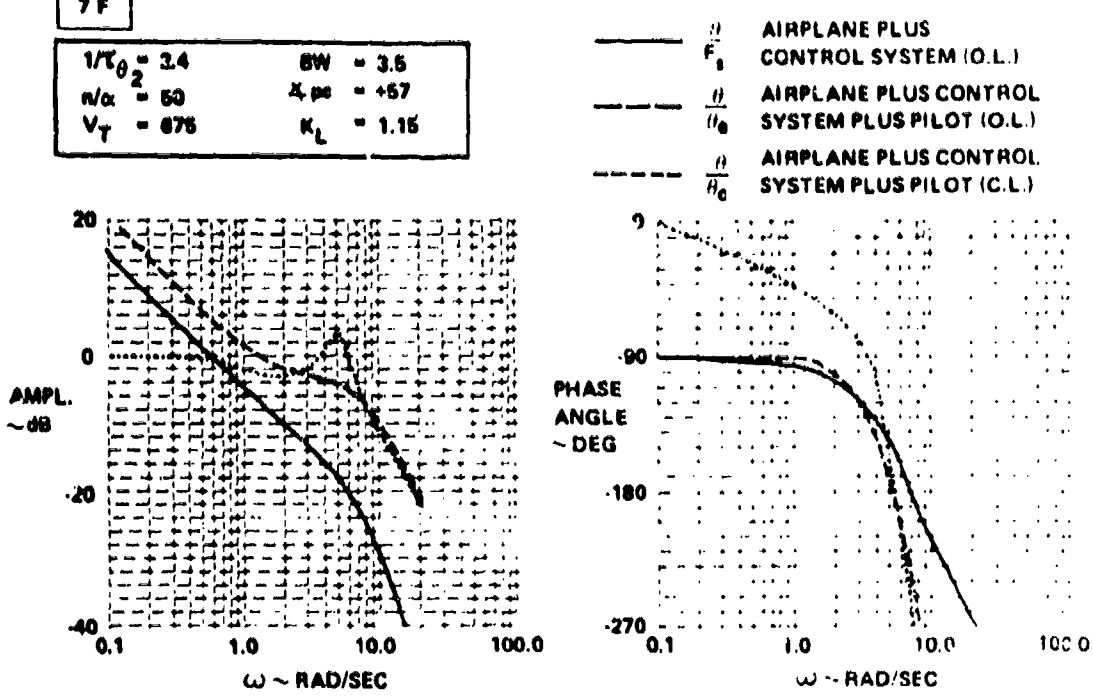
7F	CONFIGURATION ω_{sp} = 7.4 ζ_{sp} = 0.73 33.63

FLT PILOT	1032 W	1057 W	1065 M	1024 [1] W	1063 W	1064 W
PR PIOR	3 2	6 2	6 2	7	7:35	7:6
[illegible]	56049	45061	49056	50056	32086	47056
[illegible]	2345	19:36	21 39	21.40	14:28	20/2
STICK FORCES	GOOD ABLE TO PICK QUITE LIGHT FORCES SOME APPARENT LIGHTENING AFTER YOU PULL BUT NOT REALLY PRONOUNCED	A LITTLE HEAVY SELECTED THEM HEAVY TO MAKE THE AIRPLANE MORE STEADY ON TARGET NOT SURE IT REALLY DID ANY GOOD SHOULD PERHAPS HAVE SELECTED FORCES A BIT LIGHTER THE INITIAL FORCES WERE NOTICEABLY HEAVIER THAN THE STEADY FORCES	QUITE COMFORTABLE LEANING TOWARD HEAVY SIDE COULD GET BOBBLING ON TARGET WITH LIGHTER FORCES	NO REAL OBJECTIONS SOMEWHAT HEAVY	GOOD NO SECOND THOUGHTS	SEEMED O K NO REAL PROBLEM NO SECOND THOUGHTS ON THE GEARING
PREDICTABILITY OF RESPONSE	HAD SOME TENDENCY TO DIG IN BUT WASN T A CLASSIC THING AT ALL SEEMED TO BE A DELAY THERE SOMEWHERE QUITE QUICKLY ADAPTED TO IT AND WAS ABLE TO FINALLY PREDICT QUITE ACCURATELY THE FINAL RESPONSE	A LITTLE PROBLEM CONSCIOUS OF HAVING TO OVERDRIVE THE AIRPLANE TO GET IT MOVING	A PROBLEM IN BOTH PITCH ATTITUDE AND G RESPONSE INITIAL RESPONSE DELAYED THEREFORE PREDICTABILITY A PROBLEM	TENDENCY TO DIG IN GET MORE G THAN EXPECTED RESPONSE SLUGGISH	RELATIVELY POOR THERE IS A DELAY IN THE INITIAL RESPONSE THEN IT TAKES OFF FINAL RESPONSE HARD TO PREDICT	VERY POOR SLIGHT INITIAL HESITATION IN RESPONSE THE FINAL RESPONSE IS PREDICTABLE IN THE SENSE THAT THE AIRPLANE STOPS IF YOU STOP THE INPUT BUT IF YOU ACTIVELY PURSUE A TARGET YOU TEND TO SET UP AN OSCILLATION
ATTITUDE CONTROL TRACKING CAPABILITY	PRETTY GOOD SMALL BOBBLE ON TARGET BUT NOT AN INORDINATE AMOUNT	A LITTLE PROBLEM ACQUIRING TARGET 2 TO 3 OVERSHOOTS FAIRLY EASY TO INADVERTENTLY MOVE NOSE OFF TARGET	SMALL OVERSHOOT IN ACQUIRING A TARGET EVERY TIME COULD NEVER LEARN TO SUPPRESS IT GOOD ON TARGET	TENDENCY TO PIO IN TIGHT TRACKING QUITE POOR	REALLY THE POOR FEATURE OF THIS AIRPLANE NO TENDENCY TO PIO FOR GENERAL MANEUVERING BUT TRACKING OF ANY KIND LEADS TO AN OSCILLATION	VERY POOR IF FLOWN AGGRESSIVELY PULSE LIKE INPUTS TEND TO ELIMINATE OSCILLATIONS BUT TRACKING IS STILL NOT VERY PRECISE
NORMAL ACCELERATION CONTROL	TEND TO OSCILLATE IN G A LITTLE BIT 0 2 OR 0 3 TYPICAL WHEN I PULL 3 OR 4 G	NOT VERY GOOD OVERSHOOTS AND OSCILLATES WHEN ATTEMPTING TO ACQUIRE G PRECISELY	SIMILAR TO PROBLEMS WITH PITCH ATTITUDE CONTROL	UNCOMFORTABLE TO FLY GET MORE G THAN EXPECTED	SAME PROBLEM AS TRACKING	GREAT TENDENCY TO OVERCONTROL IN G EVEN FOR GROSS MANEUVERS
EFFECTS OF RANDOM DISTURBANCES	BEHAVED WELL IN ROUGH AIR	NO NEW PROBLEMS	NO PROBLEM	SHORT LOOK	THE AIRPLANE JUMPS AROUND QUITE A BIT VERY UNCOMFORTABLE	QUITE A NOTICEABLE EFFECT YOU TEND TO OSCILLATE THE AIRPLANE EVEN IN NORMAL FLIGHT IF YOU TRY TO NEGATE EFFECTS OF DISTURBANCES
IFR PROBLEMS	NOTHING NEW HERE	DIDN T DO TOO WELL BUT NO NEW PROBLEMS	NOTHING NEW	DIDN T EVALUATE	NO NEW PROBLEMS O E TRACKING TASK HAS POOR TENDENCY TOWARD PIO IN BOTH TRACKING TASKS WORST IN D E TASK	NO NEW PROBLEMS PERHAPS A BIT EASIER TO FLY IFR THAN VFR
GOOD FEATURES	PRETTY NICE FIGHTER AIRPLANE	CAN ACQUIRE TARGET CAN TRACK PRETTY WELL CAN PULL LIMIT LOAD FACTOR	SOLID STEADY AIRPLANE VERY MANEUVERABLE FORCES WERE QUITE COMFORTABLE COULD GET ON TARGET QUICKLY AND TRACK WELL	[illegible] CAPABILITY GOOD	OVERALL MANEUVERING CAPABILITIES QUITE GOOD	MANEUVERING CAPABILITY IS GOOD AS LONG AS YOU DON T TRY TO TRACK ANYTHING
OBJECTIONABLE FEATURES	I HAD MORE A PECULIARITY THAN AN OBJECTIONABLE FEATURE NON AIRPLANE LIKE RESPONSE A SMALL BOBBLE ON TARGET AND OSCILLATION IN G BUT THESE ARE MINOR	HAVE TO WORK TO PUT NOSE ON TARGET NOT REAL STEADY ON TARGET CAN T PULL G PRECISELY FORCES ARE INITIALLY HEAVY THEN LIGHTER	WOULD ALWAYS OVERSHOOT A LITTLE BIT IN PITCH ATTITUDE AND G	DIGGING IN TENDENCY	FAR OUTWEIGH THE GOOD FEATURES THE TENDENCY TOWARD A PIO IN TIGHT TRACKING TASKS NOT DIVERGENT	TENDENCY TO SET UP PIO DURING TIGHT TRACKING THESE CHARACTERISTICS ARE OBJECTIONABLE AS ARE THE EFFECTS OF DISTURBANCES

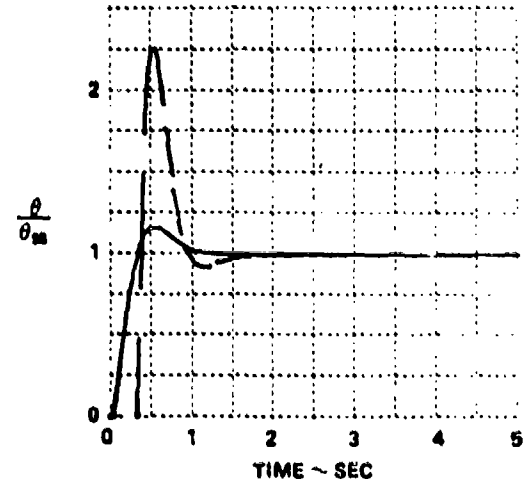
NOTE 1 EVALUATION VERY RUSHED

7 F

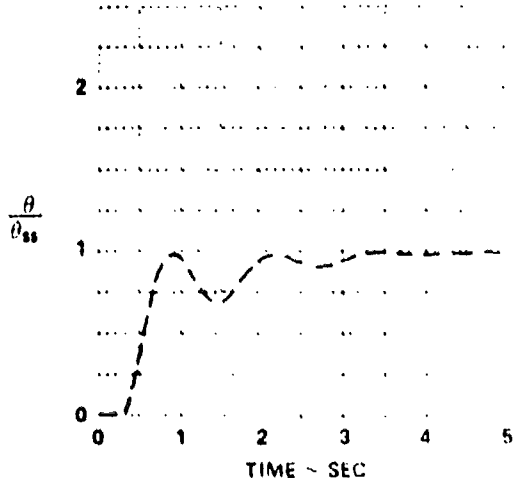
$1/\tau_{\theta_2}$	= 3.4	BW	= 3.5
n/α	= 50	Δ_{ps}	= +57
V_T	= 675	K_L	= 1.15



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



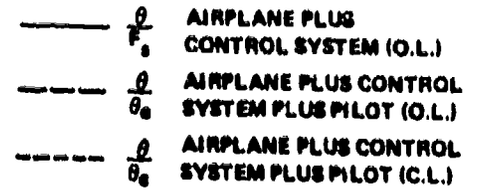
CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

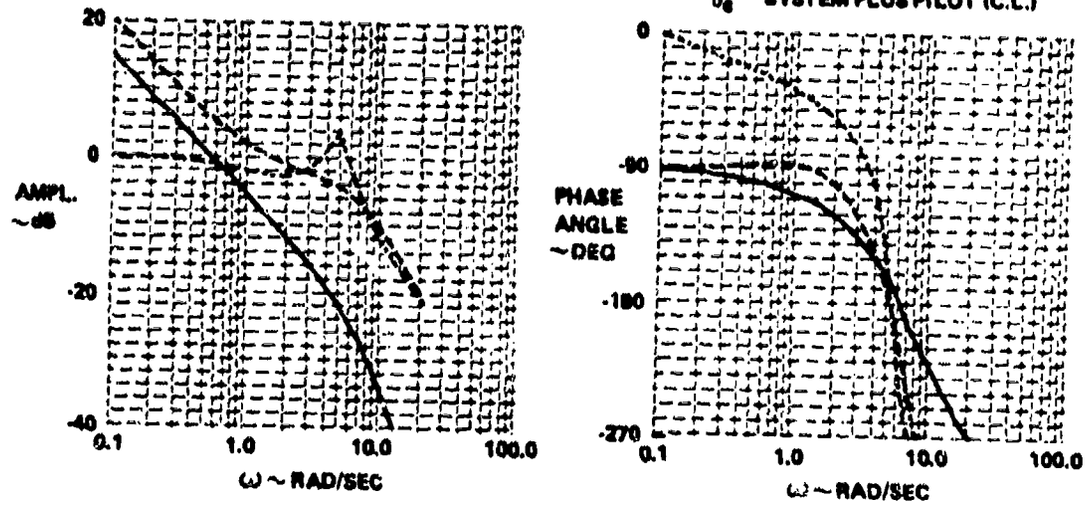
7 G	CONFIGURATION ω_{sp} = 7.3 ζ_{sp} = 0.73 – 1 2 / 63

FLT./PILOT	1068/M	1068/W
PR/PIOR	5/2	6/2
$(F_s/n)/K_{()}$	4.9/0.56	4.9/0.56
K_p/K_{DW}	1.7/5.2	1.7/5.2
STICK FORCES	A LITTLE HEAVY WOULD HAVE LIKED FORCES SOMEWHAT LIGHTER, PERHAPS, BUT GEARING USED WAS THE LIGHTEST ALLOWED.	MIGHT HAVE LIKED THEM SOMEWHAT LIGHTER, BUT GEARING USED WAS THE LIGHTEST ALLOWED. CERTAINLY SATISFACTORY HOWEVER.
PREDICTABILITY OF RESPONSE	A PROBLEM THE FORCES GO FROM HEAVY TO LIGHT TO HEAVY AGAIN AS THE RESPONSE DEVELOPS, GIVING PROBLEMS IN PULLING G AND ACQUIRING A TARGET	AIRPLANE'S RESPONSE IS VERY SLOW AND YOU THEREFORE HAVE TO USE A LARGE INITIAL INPUT AND THEN TAKE IT OUT IMMEDIATELY TO AVOID OVERCONTROLLING
ATTITUDE CONTROL TRACKING CAPABILITY	OVERSHOOTS SEVERAL TIMES IN ACQUIRING A TARGET LARGE AMPLITUDE, LOW FREQUENCY NOT A BOBBLE. NOT AS STEADY ON TARGET AS MIGHT LIKE, BUT NOT BAD	FAIR TO POOR. HAVE TO USE SHARP PULSE LIKE INPUTS. PRECISION IS NOT REAL GOOD, BUT IT IS ACCEPTABLE.
NORMAL ACCELERATION CONTROL	A PROBLEM SEEMS TO BE AN INITIAL LAG WHICH LEADS TO OVERCONTROL OF G. SORT OF A DIGGING IN TENDENCY, BUT NOT THE CLASSIC TYPE. OVERSHOOTING DOES NOT OCCUR IF YOU DON'T HAVE TO ACQUIRE G PRECISELY. HOWEVER.	SOMEWHAT DIFFICULT HAVE TO USE PULSE LIKE INPUTS TO CONTROL G REASONABLY WELL. CAN'T FLY IT AGGRESSIVELY.
EFFECTS OF RANDOM DISTURBANCES	NO NEW PROBLEMS.	NOTICEABLE EFFECT BECAUSE YOU CAN'T NEGATE THE EFFECTS OF THE RN INPUTS WHILE TRYING TO CONTROL ATTITUDE
IFR PROBLEMS	IFR TRACKING WAS CONSIDERABLY WORSE THAN VFR TRACKING, ESPECIALLY THE D E TRACKING TASK	NO NEW PROBLEMS. OVERCONTROLLING TENDENCIES SHOWED UP ON THE TRACKING TASKS, ESPECIALLY THE RN TRACKING TASK.
GOOD FEATURES	GROSS MANEUVERING IS FAIRLY GOOD	GROSS MANEUVERING CAPABILITY IS GOOD.
OBJECTIONABLE FEATURES	STEADY FORCES HEAVY FORCES GOING FROM HEAVY TO LIGHT TO HEAVY LEADS TO OVERCONTROL OF ATTITUDE AND G NOT REAL STEADY ON TARGET.	SLOW INITIAL RESPONSE AND TENDENCY TO OVERCONTROL IF FLOWN AGGRESSIVELY TRACKING CAPABILITY IS POOR AND RN DISTURBANCES ARE A PROBLEM.

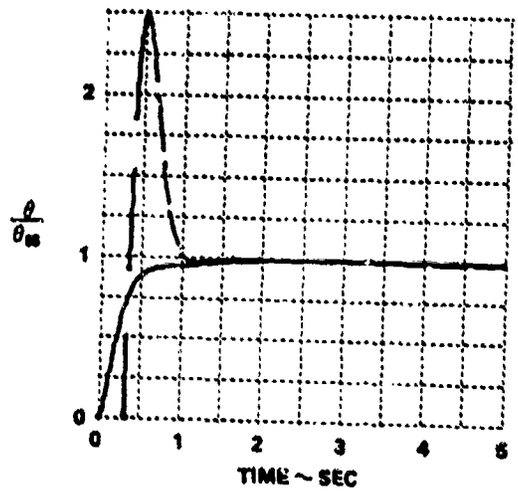
7G

$1/T_{\theta_2}$ = 2.4	BW = 3.6
$\omega_{n\alpha}$ = 50	ζ_{ps} = +/0
V_T = 575	K_L = 0.86

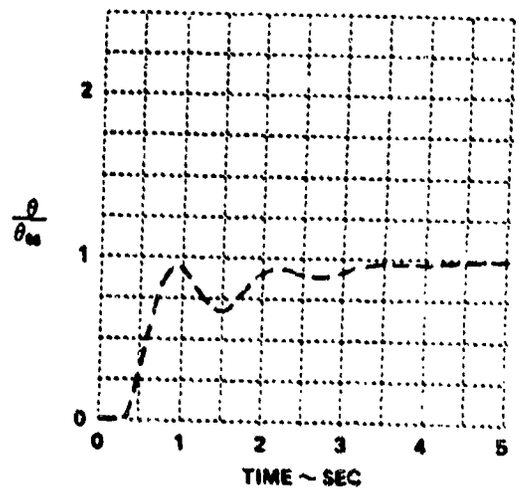




FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

7 H	CONFIGURATION ω_{sp} = 7 3 ζ_{sp} = 0 73 – / 0.8 / 63

FLT /PILOT	1061/W
PR/PIOR	5/2
$(F_s/n)/K_{\phi}$	4 7/0 58
K_p/K_{BW}	2 1/12.7
STICK FORCES	WOULD HAVE LIKED LIGHTER FORCES, BUT GEARING USED WAS LIGHTEST ALLOWED FORCES ACCEPTABLE, NO REAL PROBLEMS.
PREDICTABILITY OF RESPONSE	SLIGHT INITIAL DELAY, CAUSING YOU TO PUT IN LARGE INITIAL INPUT THEN TAKE IT OUT IMMEDIATELY CAN PREDICT FINAL RESPONSE WITH SOME ACCURACY, BUT NOT AS GOOD AS WOULD HAVE LIKED.
ATTITUDE CONTROL/ TRACKING CAPABILITY	ONLY FAIR TEND TO OVER CONTROL IT
NORMAL ACCELERATION CONTROL	RELATIVELY GOOD CAN PULL G WITH REASONABLE ACCURACY IF YOU EASE IN PUT IN
EFFECTS OF RANDOM DISTURBANCES	NOTICEABLE, TENDENCY TO OVERCONTROL
IFR PROBLEMS	NO NEW PROBLEMS TENDEN CY TO OVERCONTROL ON TRACKING TASKS
GOOD FEATURES	OVERALL MANEUVERABILITY IS QUITE GOOD
OBJECTIONABLE FEATURES	DIFFICULTY IN PREDICTING THE RESPONSE TENDENCY TO OVERCONTROL IN ATTI TUDE

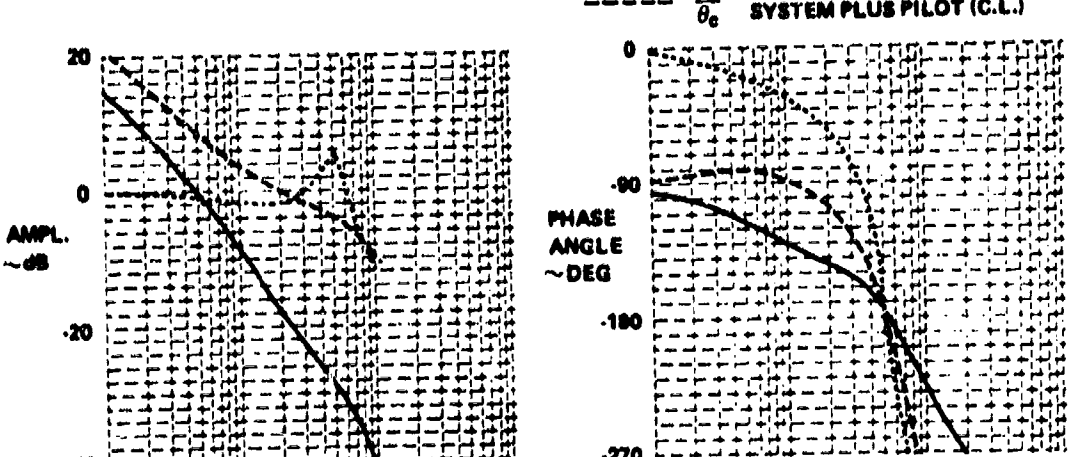
7 H

$1/T_{\theta_2}$	= 2.4	BW	= 3.5
n/α	= 50	$\angle_{ps}$	= +80
V_T	= 675	K_L	= 1.23

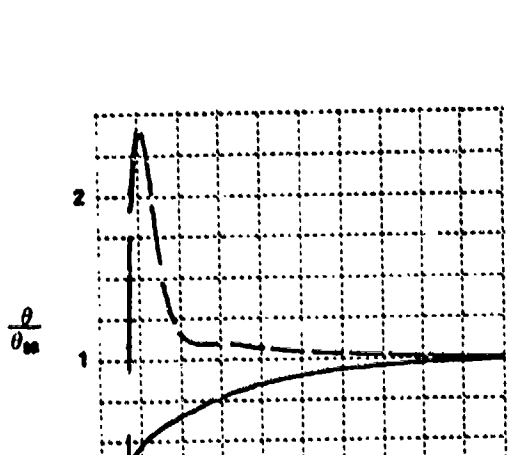
——— $\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

– – – $\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

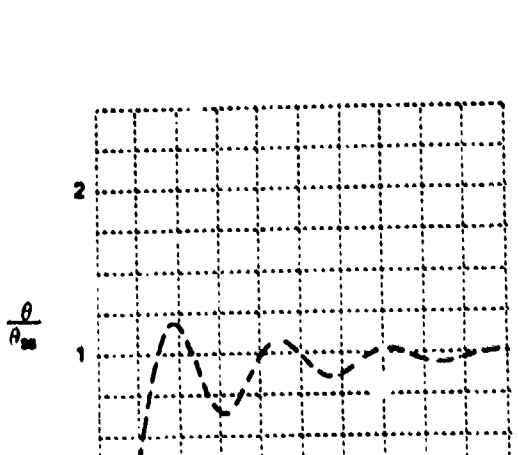
– – – – $\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

7 P	CONFIGURATION ω_{sp} = 7.3 ζ_{sp} = 0.73 -/-/ 75

PLT./PILOT	1069 ① / V.
PR/PIOR	4/1
$(F_s/\alpha)/K_\theta$	4.2/.66
K_p/K_{SW}	2.0/2.2
STICK FORCES	COMFORTABLE LIKED THEM NO SECOND THOUGHTS ON GEARING SELECTION. FORCES SEEMED SLIGHTLY SENSITIVE AROUND TRIM.
PREDICTABILITY OF RESPONSE	INITIALLY, THE AIRPLANE SEEMS TO HESITATE SLIGHTLY. THE FINAL RESPONSE IS QUITE GOOD AND FAIRLY PREDICTABLE.
ATTITUDE CONTROL/ TRACKING CAPABILITY	GOOD, BUT SOME TENDENCY TO BOBBLE. HAVE TO TAKE OUT SOME OF INITIAL INPUT IN ORDER TO ACHIEVE DE SIRED RESPONSE.
NORMAL ACCELERATION CONTROL	SLIGHT TENDENCY TO OVER-CONTROL, BUT FAIR TO GOOD
EFFECTS OF RANDOM DISTURBANCES	VERY LITTLE EFFECT ON AIR PLANE. TENDED TO EMPHA-SIZE SENSITIVITY AROUND TRIM SLIGHTLY.
IFR PROBLEMS	DIDN'T SEE ANY NEW PROB LEMS.
GOOD FEATURES	GOOD G CAPABILITY GOOD TRACKING CAPABILITY. SMOOTH TO FLY.
OBJECTIONABLE FEATURES	MINOR; SLIGHT HESITATION IN INITIAL RESPONSE.

NOTE . 1 FLOWN WITH POSITION COMMANDS.

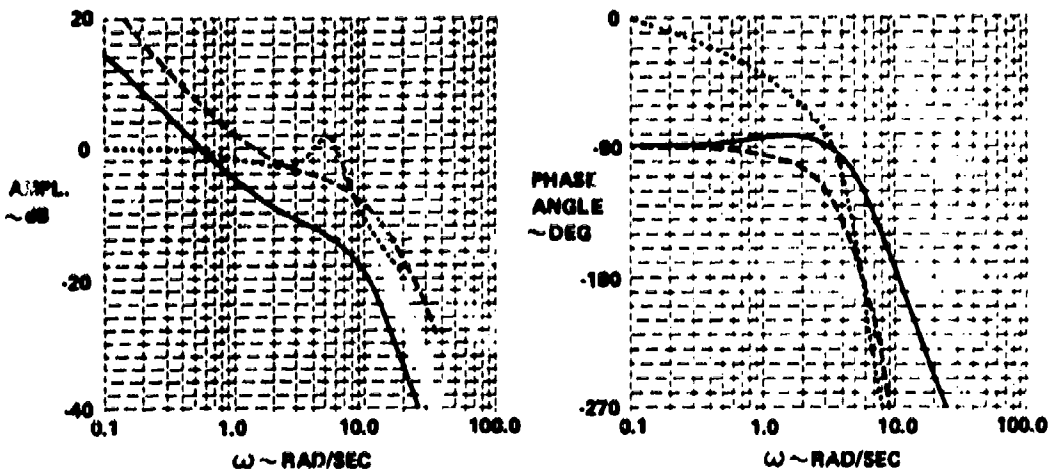
7P

$1/\tau_{\theta_2}$ = 2.4	BW = 3.5
n/α = 80	Δ_μ = +22
V_T = 675	K_L = 1.31

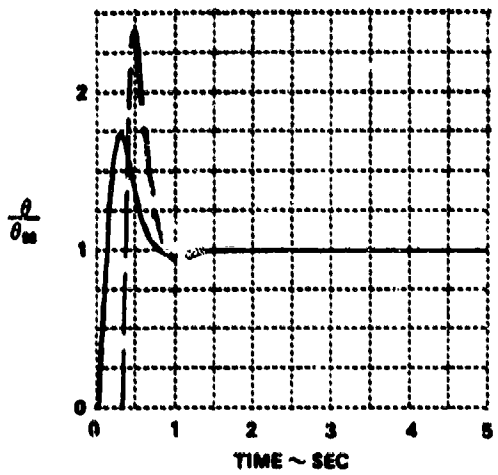
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

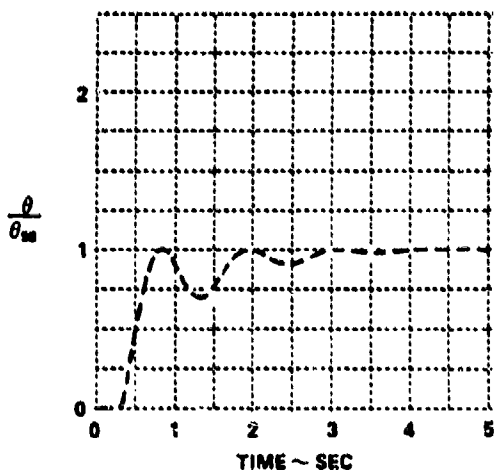
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

8 A	CONFIGURATION ω_{sp} 1.5 ζ_{sp} .069 n/α 75

FLT/PILOT	1028 M	1041/W
PR RTG	4.25	4/1
$(F_s/n)/K_{\theta}$	6.3 0.43	4.0/0.68
K_{θ}/K_{HW}	3.3/2.9	2.1/1.8
STICK FORCES	NOT O K COMPROMISE RE QUIRED BETWEEN HEAVY MANEUVERING FORCES AND TENDENCY TO WOBBLE IN PRECISION TRACKING RESULT STICK FORCES ARE HEAVY	PERHAPS SELECTED THEM TOO LIGHT FELT A DESIRE FOR A LITTLE BREAKOUT FORCE TO PREVENT INADVERTENT SMALL INPUTS
PREDICTABILITY OF RESPONSE	INITIAL FORCES VERY LIGHT BECOME HEAVIER IN STEADY TURNS PREDICTABILITY NOT TOO BAD	INITIAL RESPONSE TOO ABRUPT FINAL RESPONSE QUITE GOOD
ATTITUDE CONTROL TRACKING CAPABILITY	REAL PROBLEM WITH AIRPLANE LIES HERE WOBBLES ON TARGET NERVOUS A/C SERIOUS OBJECTION FOR THIS MISSION	GOOD
NORMAL ACCELERATION CONTROL	HIGH FREQUENCY OSCILLATIONS ABOUT A GIVEN G HOWEVER SMALL SO ACC CONTROL IS GOOD (PER SE)	GOOD
EFFECTIVE TURBULENCE PENETRATION CHARACTERISTICS	POINTS OUT THAT A/C WOULD DEGRADE RAPIDLY IN ROUGH AIR ABRUPT RESPONSE TO RN	NO MAJOR EFFECT
IFR PROBLEMS	NOTE VFR MORE PRECISE THAN IFR SO IFR LESS DEMANDING AND OSCILLATIONS WERE SMALL ENOUGH THAT FOR IFR TASKS HERE IS BETTER IFR THAN VFR NO NEW PROBLEMS IFR	SENSITIVITY AROUND TRIM POINT SHOWS UP MORE IFR THAN VFR RN TRACKING TASK WAS A BIT OF A PROBLEM BECAUSE OF SNAPPY INITIAL RESPONSE TEND TO OVERCONTROL
GOOD FEATURES	FAST AIRCRAFT G CONTROL O K	GOOD G CAPABILITY LOT OF CONFIDENCE IN FINAL RESPONSE NO BOBBLING TENDENCY. EASY TO TRIM
UNDESIRABLE FEATURES	HEAVY FORCES TO REDUCE BOBBLE BOBBLES ON TARGET NO GOOD IN ROUGH AIR CAN T TRACK PRECISELY	INITIAL RESPONSE TOO SNAPPY

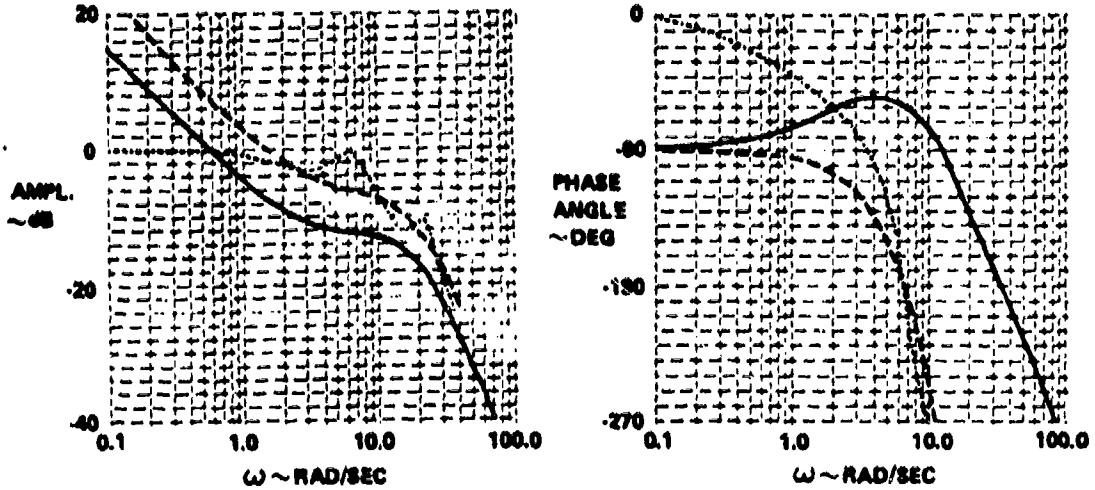
8 A

$1/\tau_{\theta_2}$ = 2.4	BW = 3.5
n/α = 50	$\Delta\phi_m$ = -10
V_T = 675	K_L = 1.43

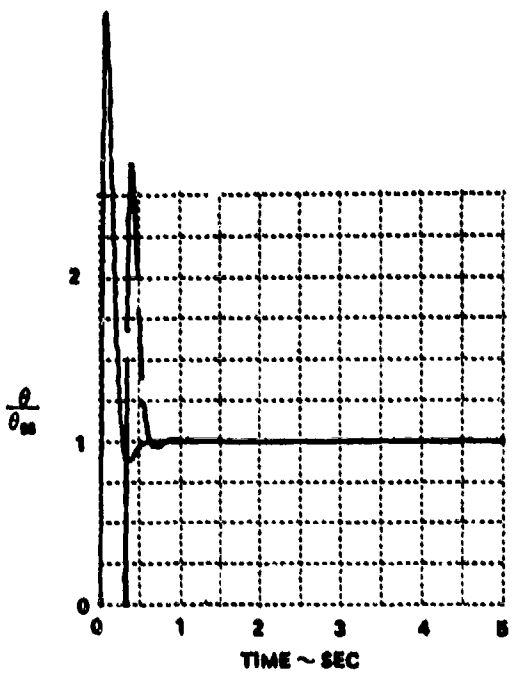
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

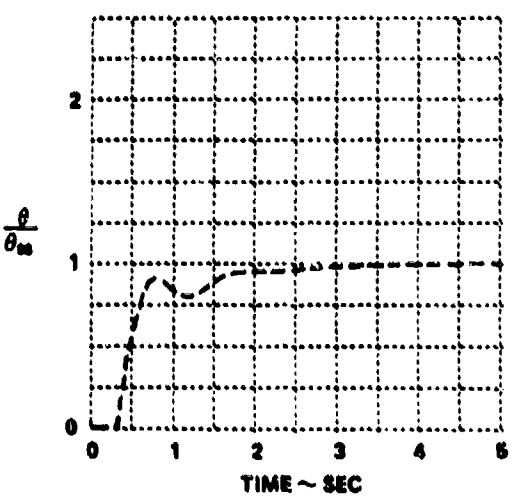
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



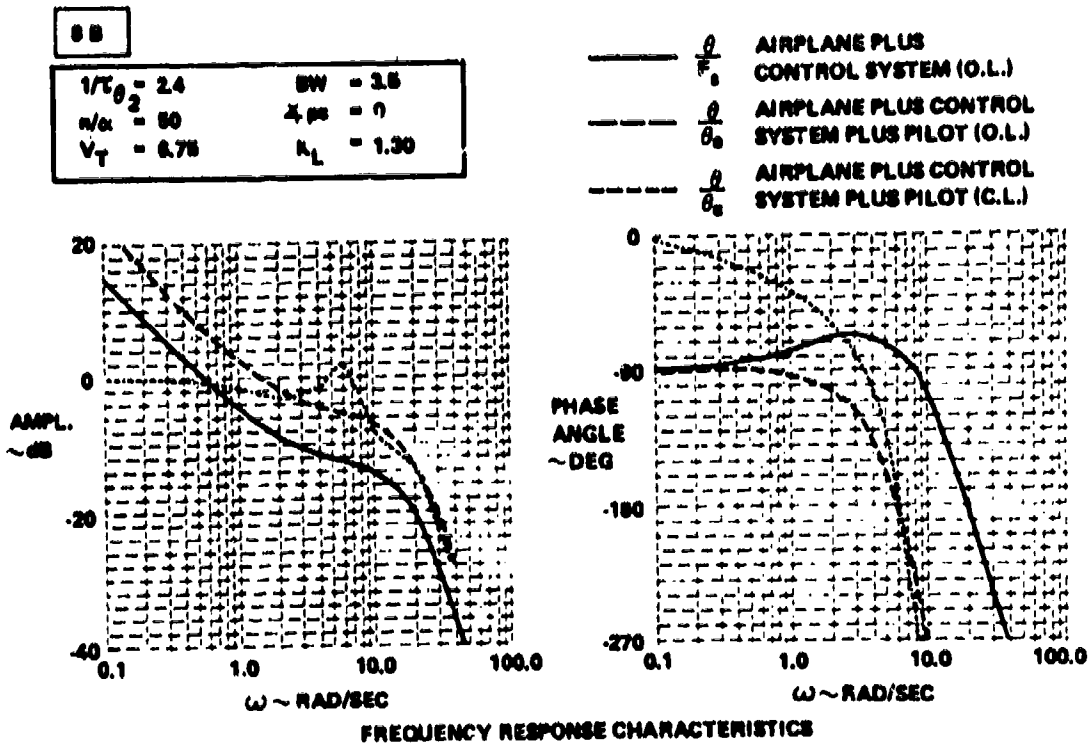
OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



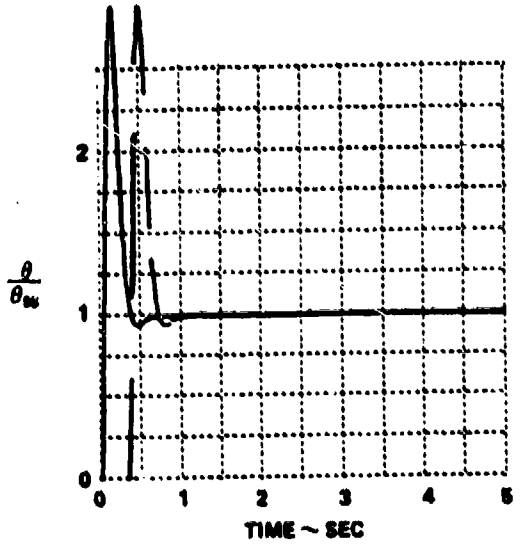
CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

88	CONFIGURATION ω_{sp} = 16.5 ζ_{sp} = 0.69 - / 19 / 83

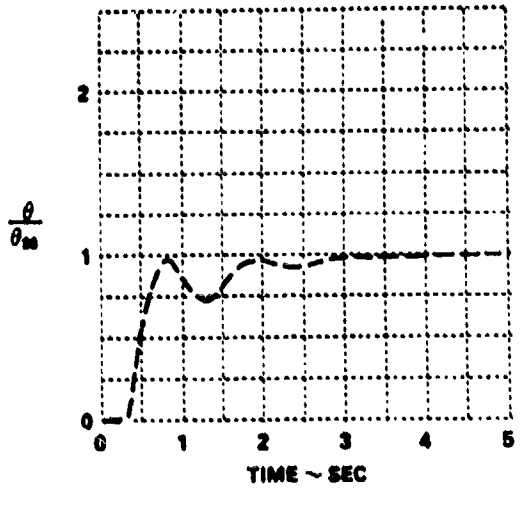
FLT./PILOT	1045/M
PR/PION	3.5/1.5
$(P_\phi/n)/K_\theta$	3.2/0.83
K_p/K_{DW}	1.6/1.6
STICK FORCES	HAD TO COMPROMISE A LITTLE BIT SINCE THIS IS QUITE A BOBBLY SORT OF AIRPLANE. HEAVIER THAN IDEAL STICK FORCES TO SUPPRESS UNWANTED INPUTS. NO SECOND THOUGHTS
PREDICTABILITY OF RESPONSE	FAIRLY PREDICTABLE NOT OUTSTANDING. INITIAL FORCES WERE QUITE LIGHT, WITH A HEAVYING UP OF FORCES WHEN YOU WENT INTO YOUR MANEUVER
ATTITUDE CONTROL/ TRACKING CAPABILITY	COULD PUT THE NOSE ON THE TARGET O.K., BUT THEN HAD A VERY SMALL AMPLITUDE HIGH FREQUENCY OSCILLATION ON TARGET. A MINOR DEFICIENCY.
NORMAL ACCELERATION CONTROL	PRETTY GOOD. SMALL TENDENCY TO OSCILLATE A LITTLE ABOUT THE G.
EFFECTS OF RANDOM DISTURBANCES	NOTHING NEW SHOWED UP.
IFR PROBLEMS	ACCENTUATED THE ABRUPT NATURE OF THE RESPONSE.
GOOD FEATURES	VERY RESPONSIVE AIRPLANE, MAYBE TOO RESPONSIVE. CAN GET IT ON TARGET PRETTY WELL. CAN PULL G QUITE ACCURATELY
OBJECTIONABLE FEATURES	SMALL OSCILLATION ON TARGET AFTER YOU ACQUIRE A TARGET AND A SORT OF ABRUPTNESS OF THE RESPONSE IN PITCH ATTITUDE AND NORMAL ACCELERATION



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

BC	CONFIGURATION ω_{sp} = 16.5 ζ_{sp} = 0.69 - / 8 / 63

PLT./PILOT	1036/M	1051/W
PR/MOR	3.5/2	3/1
$(F_s/n)/K_\theta$	5.7/0.48	3.9/0.70
K_θ/K_{BW}	2.7/2.6	1.8/1.8
STICK FORCES	STEADY-STATE FORCES WERE PRETTY HIGH TO HELP IN PRECISION TRACKING. PERHAPS SHOULD HAVE GONE LIGHTER AND ACCEPTED MORE BOBBLE ON TARGET. FORCES GO LIGHT TO HEAVY	QUITE ACCEPTABLE AND COMFORTABLE. ACCEPTABLE BAND OF ELEVATOR GEARING QUITE LARGE. NO REAL COMPROMISES INVOLVED IN SELECTION.
PREDICTABILITY OF RESPONSE	FORCES GO FROM LIGHT TO HEAVY WHICH SEEMS TO BE EASIER TO CONTEND WITH THAN REVERSE SITUATION. THINK THE FINAL RESPONSE IS PREDICTABLE	QUITE GOOD. LIKED SNAPPY INITIAL RESPONSE. WASN'T ABRUPT. FINAL RESPONSE NOT OUTSTANDING, BUT GOOD. TENDENCY TO OVER SHOOT SLIGHTLY
ATTITUDE CONTROL/ TRACKING CAPABILITY	CAN GET TO TARGET QUICKLY. THEN YOU HAVE A SMALL BOBBLE ON TARGET, DIES AWAY QUICKLY SO THAT TRACKING IS PRETTY GOOD	VERY GOOD. SLIGHT OVER SHOOTING TENDENCY. CAN FLY THE AIRPLANE AS AGGRESSIVELY AND ABRUPTLY AS DESIRED
NORMAL ACCELERATION CONTROL	VERY GOOD	EXCELLENT. GOOD G CONTROL
EFFECTS OF RANDOM DISTURBANCES	NO SPECIAL PROBLEMS.	VERY LITTLE EFFECT ON THE HANDLING QUALITIES
IFR PROBLEMS	NO SPECIAL PROBLEMS	NO NEW PROBLEMS. LIKED FLYING IT IFR
GOOD FEATURES	COULD PULL G WELL. GOOD FOR GENERAL MANEUVERING.	TRACKING. ATTITUDE CONTROL AND G CONTROL ARE ALL VERY GOOD. SNAPPY, BUT NOT OVERLY ABRUPT INITIAL RESPONSE
OBJECTIONABLE FEATURES	BOBBLE ON TARGET. STEADY G FORCES QUITE HEAVY	A VERY MINOR ONE. VERY SLIGHT OVERSHOOT IN ATTITUDE CONTROL

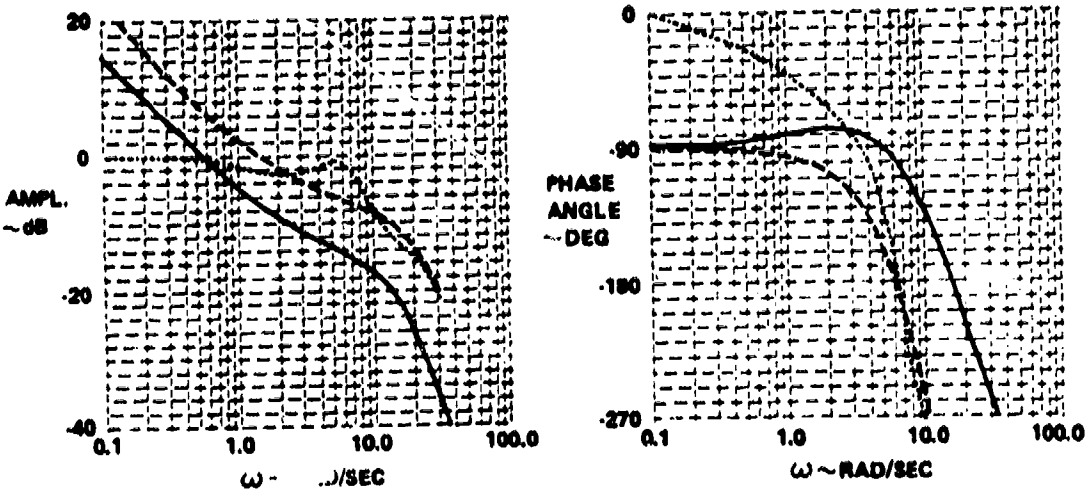
SC

$1/T_{\theta_2}$	= 2.4	BW	= 3.5
n/α	= 50	$\Delta_{\mu s}$	= +14
V_T	= 875	K_L	= 1.27

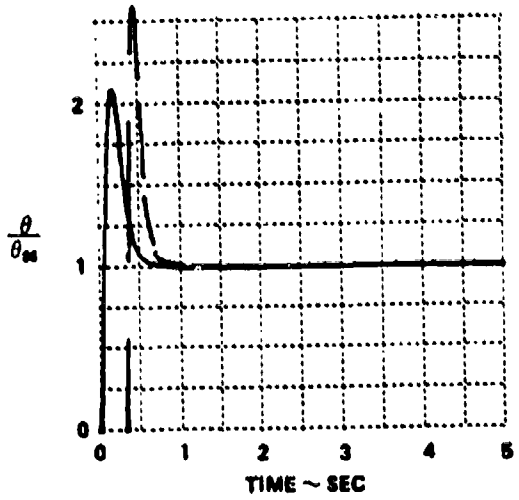
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

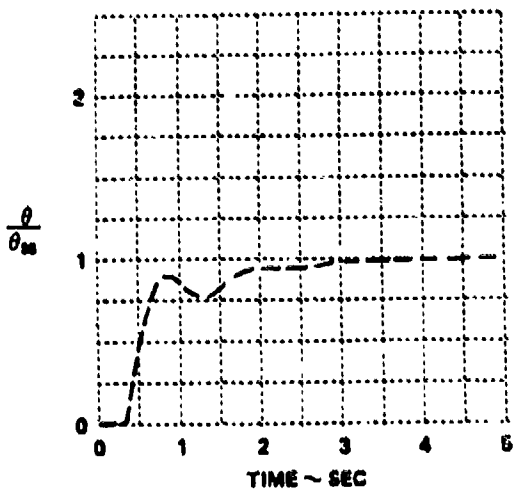
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

8D	CONFIGURATION ω_{sp} = 16.8 ζ_{sp} = 0.68 - / 3.3 / 63

FLT./PILOT	1068/M	1064/W
PR/PIOR	2/1	4/2
$(F_s/n)/K_\theta$	9.5/0.50	4.6/0.60
K_p/K_{SW}	2.6/3.4	2.2/2.8
STICK FORCES	A LITTLE HEAVY. WOULD HAVE LIKED LIGHTER FORCES, BUT GEARING USED WAS LIGHTEST ALLOWED.	NO COMPLAINTS ON GEARING SELECTED. QUITE SATISFACTORY.
PREDICTABILITY OF RESPONSE	VERY GOOD. INITIAL FORCES WERE COMPATIBLE WITH STEADY FORCES.	INITIAL RESPONSE IS QUITE GOOD, SNAPPY BUT FINAL RESPONSE OVERSHOOTS JUST ONCE WHENEVER YOU FLY IT AGGRESSIVELY
ATTITUDE CONTROL/ TRACKING CAPABILITY	NOT OUTSTANDING, BUT GOOD. COULD BE STEADIER ON TARGET	GOOD WITH THE EXCEPTION OF THE ONE OVERSHOOT ON TARGET.
NORMAL ACCELERATION CONTROL	VERY GOOD	CAN SEE AN OVERSHOOT IN G; CAN'T LEARN TO GET RID OF IT.
EFFECTS OF RANDOM DISTURBANCES	NO NEW PROBLEMS.	NO MAJOR EFFECTS.
IFR PROBLEMS	NONE	NO NEW PROBLEMS THE OVERSHOOT IN VFR TRACKING ALSO SHOWS UP IN THE D. E. TRACKING TASK.
GOOD FEATURES	EXTREMELY GOOD FIGHTER.	MANEUVERING CAPABILITY IS GOOD. A VERY GOOD FIGHTER.
OBJECTIONABLE FEATURES	STEADY FORCES ARE A LITTLE HEAVY NOT REAL STEADY ON TARGET	CAN'T STOP THE ONE OVER SHOOT DURING TIGHT TRACKING, NOT THAT BAD.

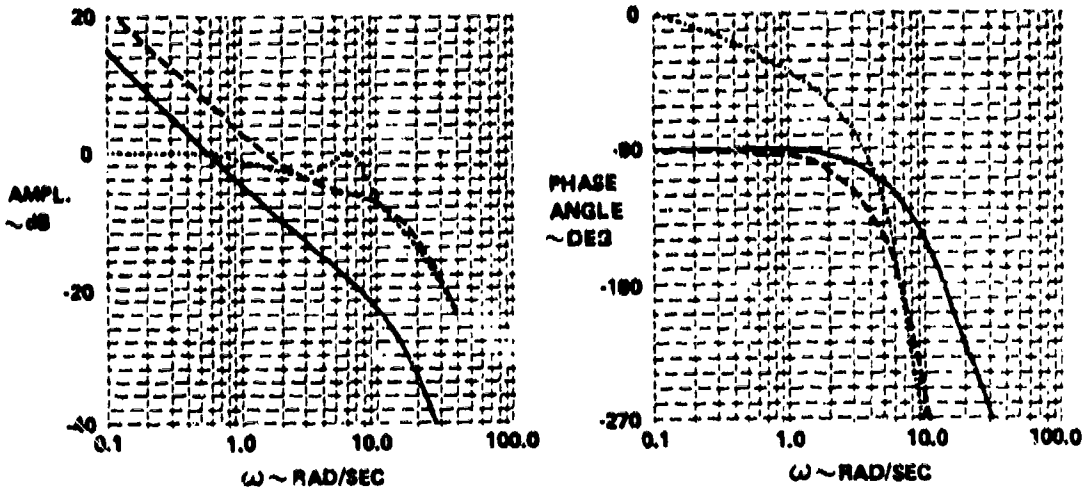
8 D

$1/\tau_{\theta_2}$ = 2.4	BW = 2.5
n/α = 60	$\angle_{pk}$ = +36
V_T = 675	K_L = 1.31

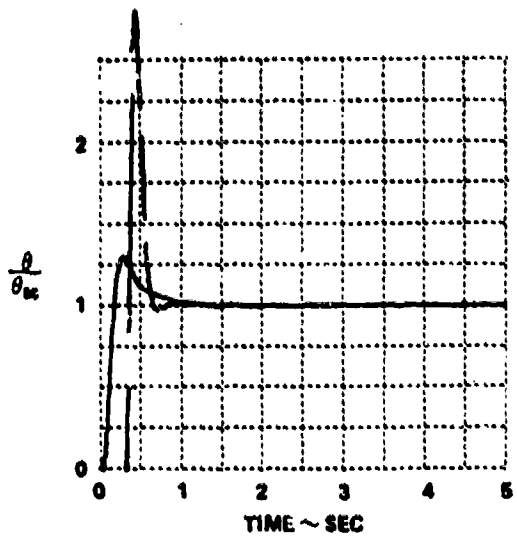
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

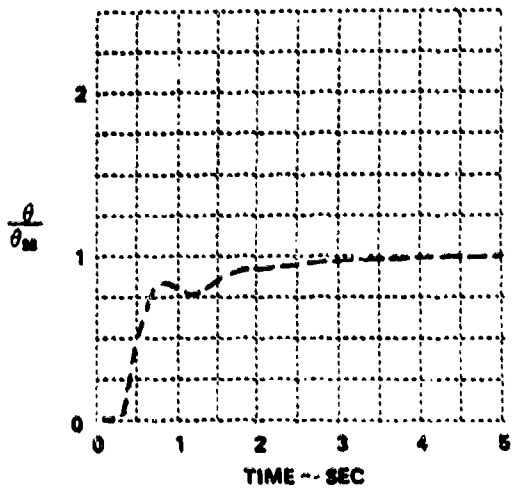
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR C_s IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

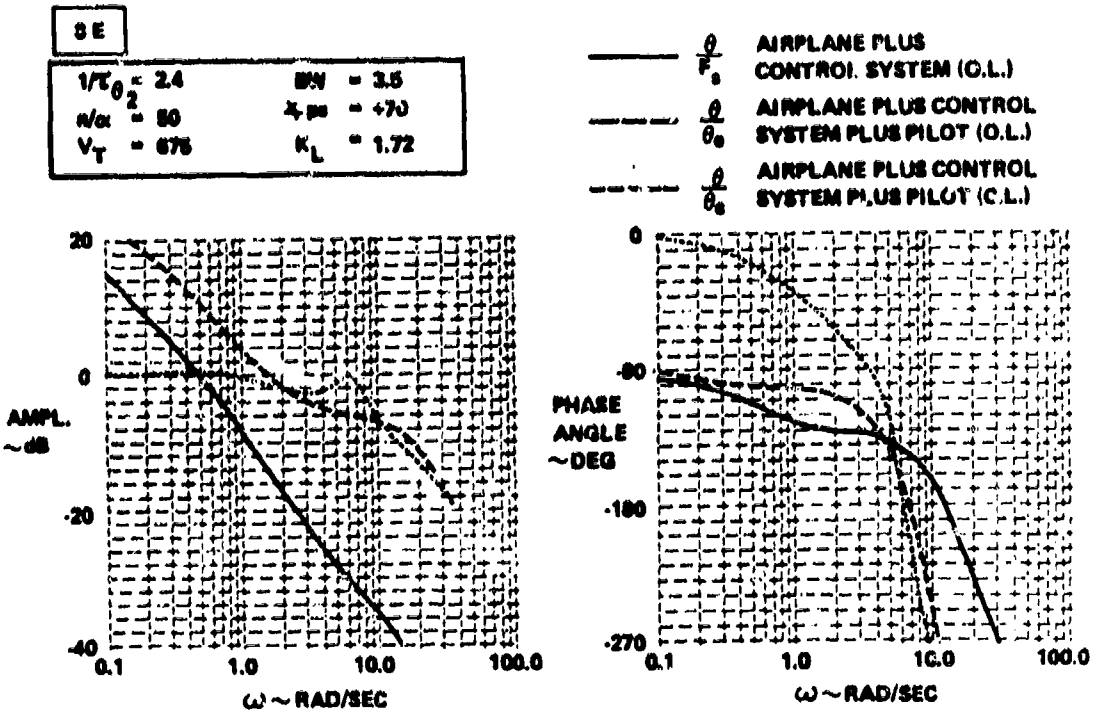
8 E	CONFIGURATION ω_{sp} = 16.5 ζ_{sp} = 0.60 – / 0.6 / 63

FLT./PILOT	1063/M	1070①/M	1067/W
PR/PIOR	2.5/1	3/1	5/2
$(F_s/n)/K_\theta$	4.6/0.60	4.6/0.60	4.6/0.60
K_ρ/K_{BW}	2.9/0.6	2.9/0.6	2.9/0.6
STICK FORCES	INITIAL FORCES A LITTLE HEAVY. MIGHT HAVE PREFERRED SOMETHING LIGHTER, BUT THE FORCES USED WERE THE LIGHTEST ALLOWED.	SEEMED O.K. - WASN'T REALLY CONSCIOUS OF THEM.	TOO HEAVY FOR FIGHTER MISSION. WOULD HAVE SELECTED LIGHTER BUT NOT ALLOWED TO DO SO.
PREDICTABILITY OF RESPONSE	VERY GOOD. IN GENERAL. JUST A LITTLE SLUGGISH.	SEEMED PRETTY GOOD. FORCES SEEMED TO GO FROM HEAVY TO LIGHT. IF ANYTHING, BUT NOT VERY MUCH.	AIRPLANE IS PREDICTABLE EVEN THOUGH IT COMES ALONG SLOWER THAN DESIRABLE. CAN STOP ON TARGET BY ADAPTING PROPER CONTROL TECHNIQUE BUT THEN TENDS TO WANDER OFF TARGET
ATTITUDE CONTROL/ TRACKING CAPABILITY	GOOD. OVERSHOOTS A LITTLE IN ACQUIRING A TARGET, BUT SOLID AS A ROCK ONCE YOU'RE ON TARGET.	SEEMED GOOD. A LITTLE TROUBLE ACQUIRING A TARGET BUT NOT MUCH.	FOOLS YOU A BIT IN THAT ONCE ON TARGET IT WILL WANDER OFF. CAN EASILY BE BROUGHT BACK SO PROBLEM IS NOT A MAJOR ONE
NORMAL ACCELERATION CONTROL	GOOD. NOT THE PRECISION OF CONTROL THAT YOU MIGHT LIKE.	SEEMED PRETTY GOOD.	PRETTY GOOD BUT NOT RAPID ENOUGH.
EFFECTS OF RANDOM DISTURBANCES	NO NEW PROBLEMS.	DIDN'T LOOK AT IT.	NO PROBLEMS.
IFR PROBLEMS	NO NEW PROBLEMS.	DIDN'T LOOK AT IT.	NOTHING NEW. SOME TENDENCY TO RIDE OFF TARGET SHOWS UP IN D. E. TRACKING TASK. SLOW AIRPLANE RESPONSE MAKES PERFORMANCE POOR ON AN TRACKING TASK
GOOD FEATURES	VERY GOOD AIRPLANE. CAN MANEUVER QUICKLY AND PRECISELY. TRACKING VERY GOOD.	QUITE MANEUVERABLE. COULD TRACK PRETTY WELL. FORCES PRETTY GOOD PERHAPS A LITTLE HEAVY	TRIM CONTROL. ABILITY TO STOP AIRPLANE ON TARGET
OBJECTIONABLE FEATURES	SOME INITIAL SLUGGISHNESS. INITIAL FORCES A LITTLE HEAVY.	A LITTLE PROBLEM IN ACQUIRING A TARGET NOT REAL STEADY.	TENDS TO WANDER OFF TARGET. HIGH STICK FORCES. SLOW MANEUVERING CHARACTERISTICS. MUST OVER DRIVE AIRPLANE AND THIS ACCENTUATES HEAVY FORCES

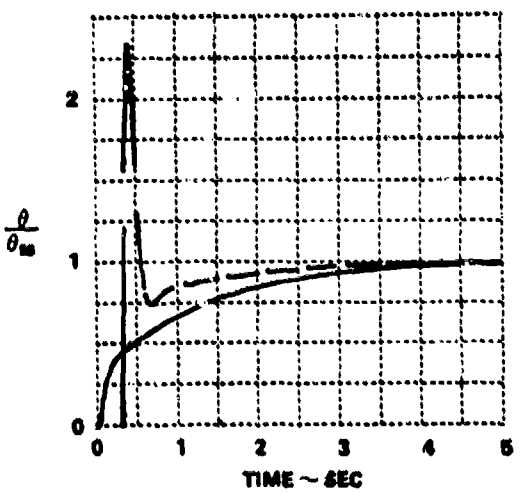
NOTE ① EVALUATION VERY RUSHED

S E

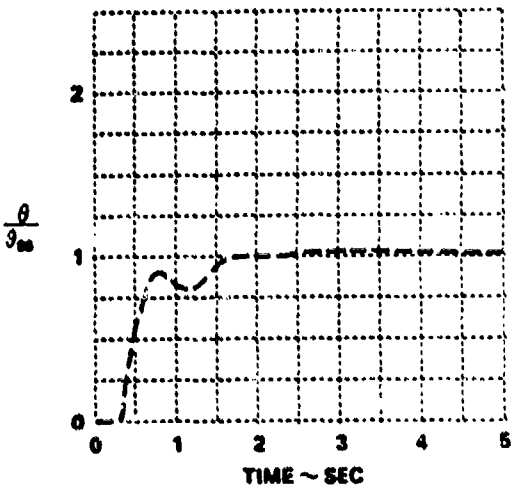
$1/\tau_{\theta_2}$	= 2.4	BW	= 3.5
n/α	= 50	Δ_{PM}	= +70
V_T	= 675	K_L	= 1.72



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



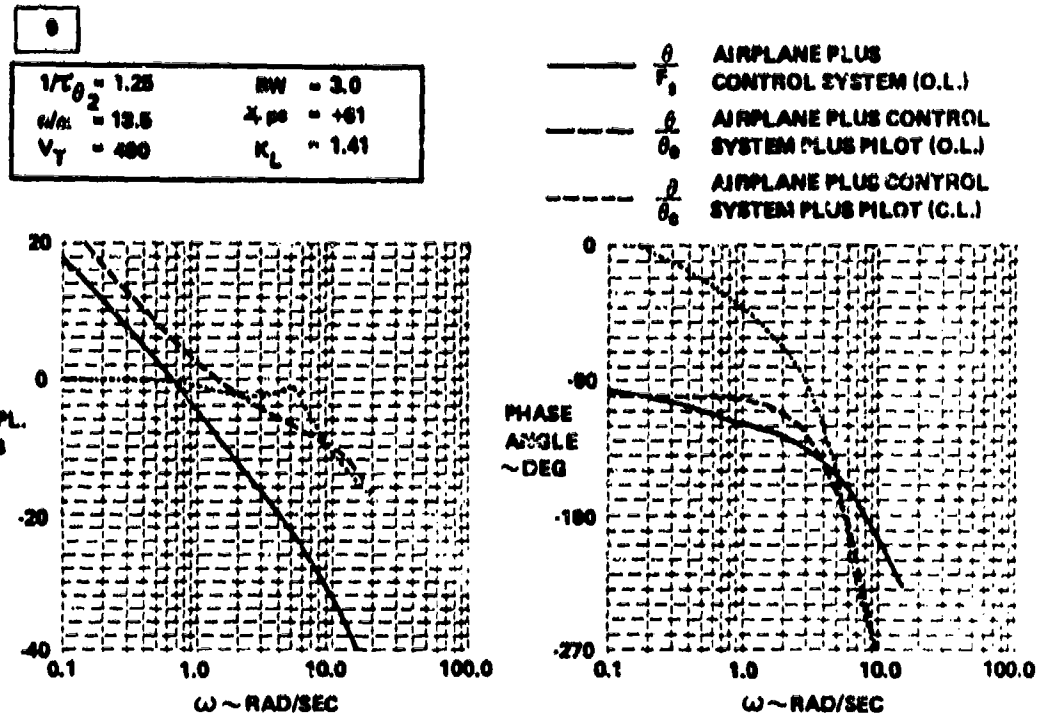
CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

9	CONFIGURATION ω_{sp} = 2.3 ζ_{sp} = 1.7 -/-/75

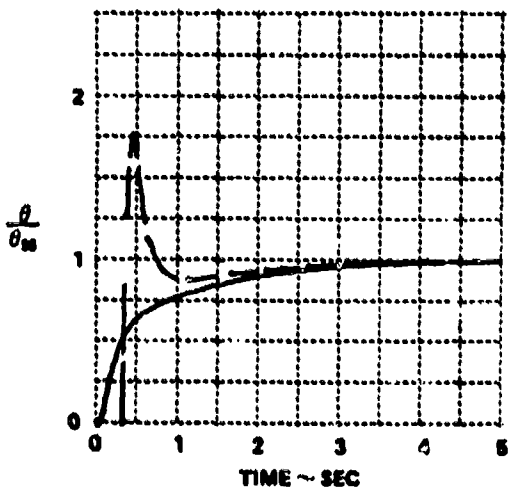
PLT./PILOT	1060 ① /M	1070 ② /M
PR/PICR	6/2	6/2
$(F_s/n)/K_\theta$	3.4/1.13	9.7/.48
K_θ/K_{BW}	1.25/2.8	3.5/7.9
STICK FORCES	QUITE LIGHT. INITIAL FORCES GOT A LITTLE HEAVY AFTER A WHILE, SO MIGHT HAVE SELECTED LIGHTER FORCES. BUT GEARING SELECTED IS NOT FAR OFF.	STEADY FORCES ARE O.K. BUT INITIAL FORCES ARE QUITE HEAVY. WOULD HAVE LIKED FORCES A BIT LIGHTER.
PREDICTABILITY OF RESPONSE	NOT VERY GOOD IN G. MARKED LIGHTENING OF FORCES DURING MANEUVERS, LEADING TO OVERCONTROL	EXTREMELY SLUGGISH AIRPLANE. PREDICTABILITY NOT TOO GOOD BECAUSE THE FORCES GO FROM HEAVY TO LIGHT AS THE RESPONSE DEVELOPS BUT THE FACT THE RESPONSE IS SO SLOW DOES GIVE YOU TIME TO FIGURE OUT WHERE THE NOSE IS GOING, SO THAT THE PREDICTABILITY IS NOT TOO BAD EITHER
ATTITUDE CONTROL TRACKING CAPABILITY	NOT REALLY TOO BAD HAVE TO NOTICEABLY DRIVE THE AIRPLANE TO MOVE NOSE, EVEN THOUGH STEADY FORCES ARE LIGHT. NOSE STAYS PUT ON TARGET	AWFUL LOT OF WORK TO ACQUIRE TARGET BECAUSE THE INITIAL FORCES ARE SO HEAVY AND BECAUSE IT TAKES SO LONG TO GET THERE. BUT ITS STEADY ONCE YOU'RE ON TARGET
NORMAL ACCELERATION CONTROL	THERE IS A PROBLEM HERE. FORCES GO FROM VERY HEAVY TO LIGHT. HAVE TO CHECK FORWARD VERY RAPIDLY AS RESPONSE DEVELOPS TO KEEP FROM OVERSHOOTING DESIRED G.	IT'S HARD WORK, AND THERE'S A TENDENCY TO DIG IN. YOU DEFINITELY OVER SHOOT THE DESIRED G
EFFECTS OF RANDOM DISTURBANCES	DION'T SHOW UP ANY PROBLEMS.	NOTHING NEW HERE - JUST MAKES A HECK OF A LOT OF WORK.
IFR PROBLEMS	NO NEW PROBLEMS. NORMAL ACCELERATION CONTROL AND TRACKING TASKS WERE SOMEWHAT MORE DIFFICULT THAN VFR TASKS.	CAN DO MOST OF THE IFR TASKS PRETTY WELL, BUT HAVE MORE TROUBLE PULLING G ACCURATELY IFR THAN VFR.
GOOD FEATURES	STEADY ON TARGET. COULD ACQUIRE A TARGET O.K. (SOME EFFORT REQUIRED) STEADY FORCES COMFORTABLE	CAN PULL LIMIT LOAD FACTOR O.K. IT'S PRETTY STEADY ON TARGET, ONCE YOU GET THERE.
OBJECTIONABLE FEATURES	FORCES HEAVY INITIALLY, THEN LIGHTER HAVE TO OVERDRIVE TO GET AIRPLANE MOVING. TENDS TO DIG IN WHEN MANEUVERING.	INITIAL FORCES FEEL VERY HEAVY INDEED TAKES A FAIR TIME TO GET THE NOSE ONTO A TARGET. THE FORCES LIGHTEN CONSIDERABLY AS THE RESPONSE DEVELOPS, SO THAT YOU HAVE TO CHECK FORWARD TO AVOID OVERCONTROL

NOTE ① FLOWN WITH FORCE COMMANDS.

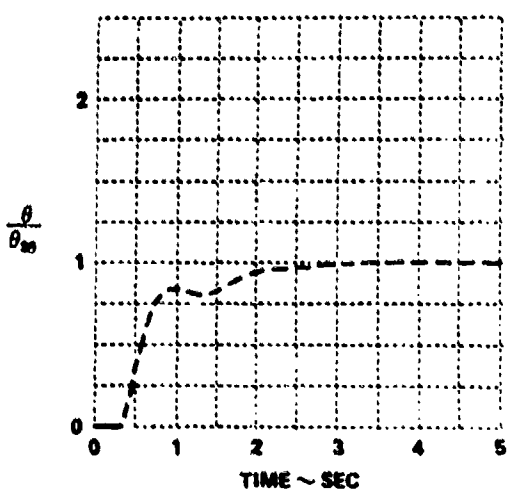
NOTE ② FLOWN WITH POSITION COMMANDS, F/N HIGH LIMITS INCORRECTLY SET.



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

10	CONFIGURATION ω_{sp} = 2.3 ζ_{sp} = 1.2 – / – / 75

PLT/PILOT	1045 ① /M	1075 ② /M
PR/PIOR	4/1.5	4/1.5
$(P_s/n)/K_{()}$	2.6/1.37	8.2/.47
K_p/K_{BW}	.74/1.7	2.1/4.8
STICK FORCES	LIGHT ENOUGH. NO SECOND THOUGHTS ON GEARING SELECTION.	INITIAL FORCES ARE A LITTLE HEAVY, BUT LIGHTER FORCES MIGHT MAKE THE AIRPLANE NOT SO STEADY ON TARGET SO THE FORCES MIGHT HAVE BEEN SELECTED A BIT LIGHTER, BUT IT'S A TRADEOFF
PREDICTABILITY OF RESPONSE	NOT TERRIBLY GOOD HEAVY INITIAL FORCES FOLLOWED BY LIGHTER FORCES SOME TENDENCY TO OVERSHOOT, DIG IN.	NOT TOO GOOD THE INITIAL FORCES FEEL INITIALLY HEAVY, THEN GO LIGHTER AS THE RESPONSE DEVELOPS, CAUSING YOU TO OVERSHOOT IN G AND MAKING THE RESPONSE SOMEWHAT UNPREDICTABLE.
ATTITUDE CONTROL/ TRACKING CAPABILITY	STEADY ON TARGET, BUT REQUIRES EFFORT TO MOVE FROM ONE TARGET TO ANOTHER.	NOT TOO BAD AS A MATTER OF FACT IT'S QUITE GOOD YOU HAVE TO WORK AND OVERDRIVE IT TO MOVE THE NOSE, BUT IT SETTLES DOWN QUITE QUICKLY AND IS VERY STEADY ON TARGET
NORMAL ACCELERATION CONTROL	MARKED TENDENCY TO OVER SHOOT DESIRED G BUT CAN LEARN TO COMPENSATE FOR IT PRETTY WELL	NOT VERY PRECISE THIS IS MAIN PROBLEM WITH AIRPLANE TENDS TO OVERSHOOT AND DIG IN
EFFECTS OF RANDOM DISTURBANCES	NOT TOO MUCH SHOWED UP HERE	NO PROBLEM AT ALL
IFR PROBLEMS	NOTHING REALLY SHOWED UP HERE	COULDN'T DO IFR TRACKING TASKS VERY WELL
GOOD FEATURES	VERY STEADY ON TARGET NOT TOO BAD FOR ACQUIRING A TARGET (A BIT OF A PROBLEM THOUGH) FORCES ARE LIGHT CAN PULL G	VERY STEADY ON TARGET CAN MOVE FROM TARGET TO TARGET QUITE WELL STEADY FORCES ARE QUICK, COMFORTABLE
OBJECTIONABLE FEATURES	ACQUIRING TARGET IS A BIT OF A PROBLEM	INITIAL FORCES ARE QUITE HEAVY DIFFICULT TO PULL G ACCURATELY YOU OVER SHOOT SOMEWHAT

NOTE ① FLOWN WITH FORCE COMMANDS

NOTE ② FLOWN WITH POSITION COMMANDS F/N HIGH LIMITS INCORRECTLY SET

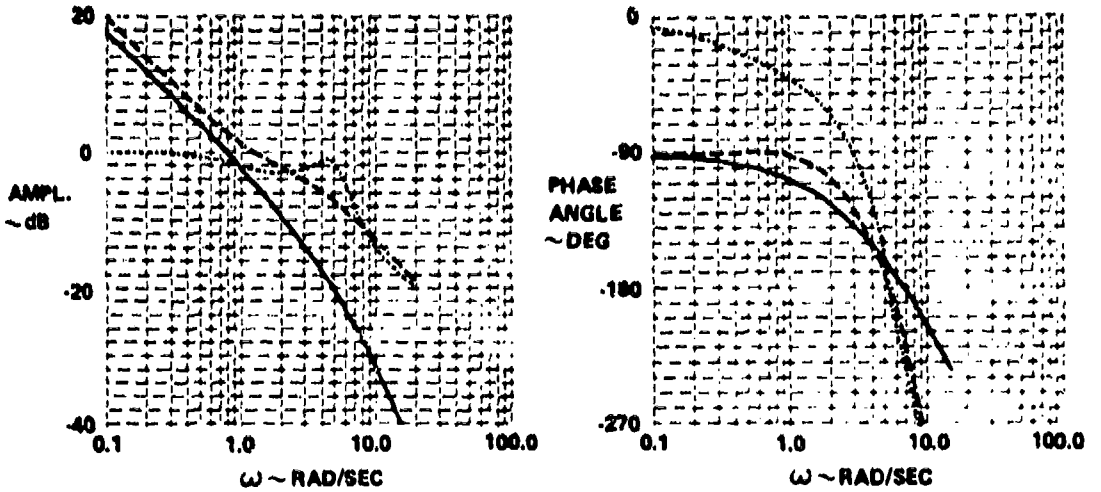
10

$1/T_{\theta_2}$ = 1.25	BW = 3.0
n/α = 18.5	ϕ_{pc} = +63
V_T = 480	K_L = 1.01

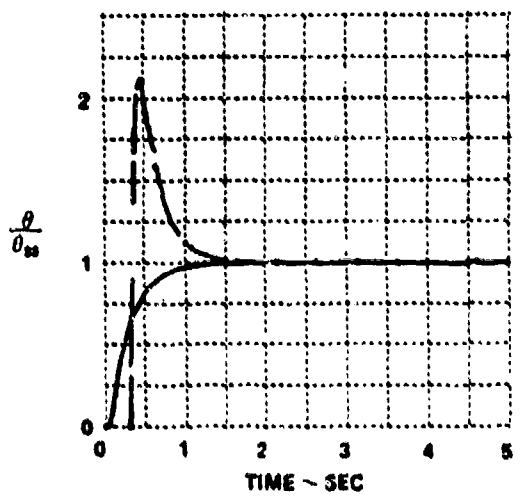
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

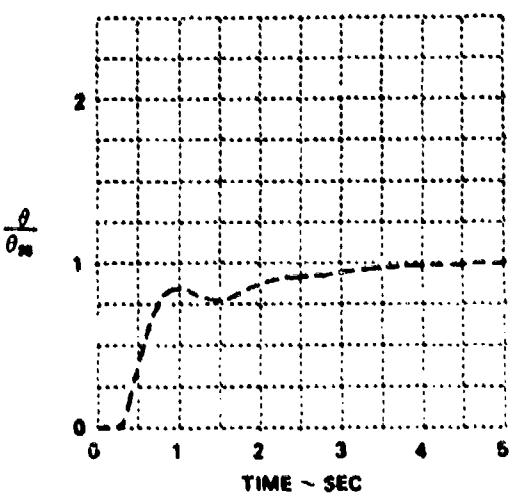
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

11	CONFIGURATION ω_{sp} = 3.3 ζ_{sp} = 1.1 - / - / 75

FLT./PILOT	1060①/M	1065②/M
PR/PIOR	2.5/1	3/1
$(P_\phi/n)/K_{()}$	5.1/ 75	7.6/.49
K_ϕ/K_{BW}	1.36/1.9	2.1/2.9
STICK FORCES	GOOD. LIGHT. PLEASANT. COULD HAVE POSSIBLY SELECTED LIGHTER FORCES, BUT NOT MUCH LIGHTER	A LITTLE ON THE HEAVY SIDE. WOULD HAVE PREFERRED LIGHTER FORCES.
PREDICTABILITY OF RESPONSE	PRETTY GOOD. FORCES SEEM TO LIGHTEN AS RESPONSE DEVELOPS, INDICATING I AM OVERDRIVING THE AIRPLANE A BIT.	GOOD. AIRPLANE NOT QUITE AS RESPONSIVE AS YOU MIGHT HAVE LIKED. A MINOR COMPLAINT
ATTITUDE CONTROL. TRACKING CAPABILITY	VERY GOOD OUTSTANDING FEATURE OF AIRPLANE CAN ACQUIRE TARGET EASILY SOME SMALL OVER DRIVING NECESSARY, BUT IS A MINOR FACTOR VERY STEADY ON TARGET	COULD ACQUIRE TARGET QUITE WELL AS GOOD AS YOU COULD EXPECT
NORMAL ACCELERATION CONTROL	PRETTY GOOD. SOME SMALL OVERSHOOTING TENDENCY IN PULLING G.	VERY GOOD
EFFECTS OF RANDOM DISTURBANCES	NO PROBLEM	NO PROBLEMS AT ALL
IFR PROBLEMS	NO NEW PROBLEMS.	VERY GOOD IN D E TRACKING TASK
GOOD FEATURES	PRETTY NICE FIGHTER. NICE LIGHT FORCES. ATTITUDE CONTROL OUTSTANDING MANEUVERABILITY IS GOOD.	GOOD SOLID AIRPLANE STEADY GUN PLATFORM, CAN ACQUIRE TARGET REALLY QUITE RAPIDLY CAN TRACK WELL AND PULL G QUICKLY AND PRECISELY
OBJECTIONABLE FEATURES	HAVE TO OVERDRIVE IT A LITTLE TO GET IT MOVING INITIALLY MINOR OBJECTION	FORCES SOMEWHAT HEAVY

NOTE ① FLOWN WITH FORCE COMMANDS

NOTE ② FLOWN WITH POSITION COMMANDS, F/N HIGH LIMITS INCORRECTLY SET

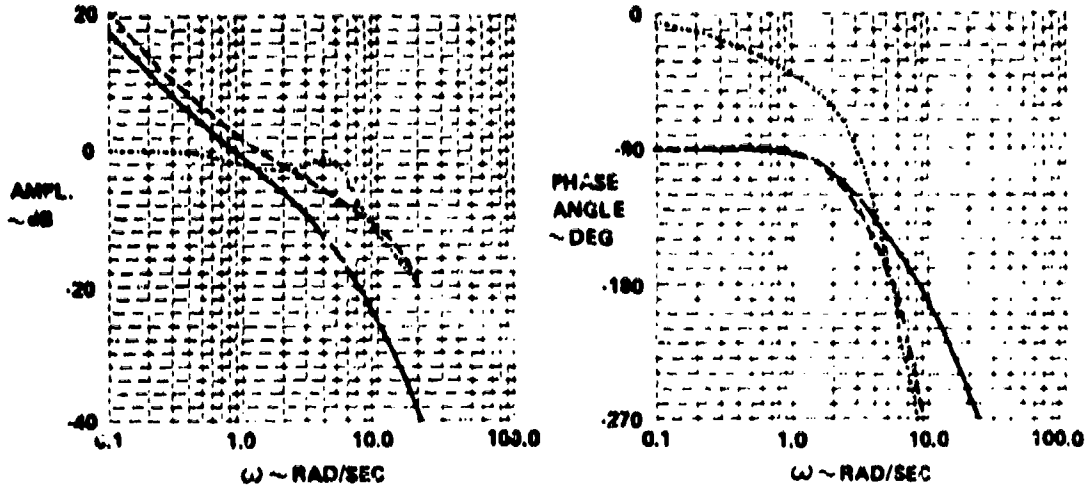
11

$1/T_{\theta_2}$	= 1.25	BW	= 3.0
ω/α	= 18.6	$\Delta\phi_M$	= + 45
V_T	= 480	K_L	= 1.01

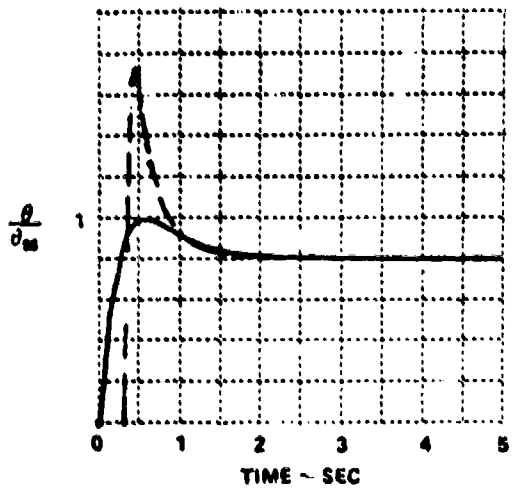
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

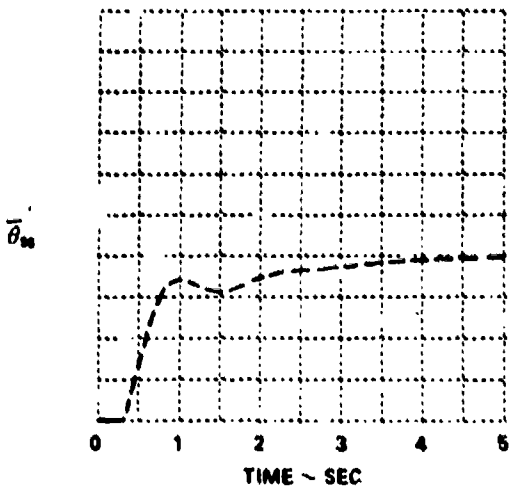
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

12	CONFIGURATION (1) ω_{sp} = 10 ζ_{sp} = .46 - / - / 75

FLT /PILOT	1062/M	1071 (2) / M	1073 (2) / W
PR/PIOR	3/2.5	6/2.5	6/3
$(\beta_q/n)/R_{(}$	4.6/.66	8.4/.33	8.3/.31
R_p R_{PW}	2.2/2.2	3.7/3.7	3.7/3.6
STICK FORCES	HEAVY, BUT SELECTED THAT WAY TO HELP TRACKING ABILITY. GEARING SELECTED SEEMED REASONABLE	HEAVY. HEAVY. CAN PULL REQUIRED G LOAD. SO MAY BE IT'S THE BEST COMPROMISE AVAILABLE. CONSIDERING THE ABRUPT INITIAL RESPONSE	HEAVIER THAN DESIRED ADMITTEDLY, THE FORCES ALLOWED MADE A BETTER TRACKING AIRPLANE BUT MANEUVERING IS DIFFICULT.
PREDICTABILITY OF RESPONSE	FORCES ARE INITIALLY LIGHT BECOMING HEAVY AS RESPONSE DEVELOPS. PREDICTABILITY OF RESPONSE IS GOOD FOR G CONTROL, POOR FOR ATTITUDE CONTROL	LARGE PITCH RATE OVERSHOOT. VERY BAD IN PITCH WORSE THAN IN G. EXTREMELY LIGHT INITIAL FORCES. THEN HEAVY RIGHT UP WHEN PULLING G	INITIAL RESPONSE PRETTY GOOD. FINAL RESPONSE IS A PROBLEM. ALWAYS GET 3 OR 4 OSCILLATIONS ABOUT THE TARGET
ATTITUDE CONTROL TRACKING CAPABILITY	VERY POOR. VERY DIFFICULT TO ACQUIRE TARGET. LIGHT ON TARGET. NOT STEADY ON TARGET. WANDERS.	VERY POOR. GET 3, 4, 5 OVERSHOOTS BEFORE SETTLING DOWN ON TARGET. THEN ONLY FAIR ON TARGET	FAIR TO POOR BUT CAN STILL DO THE JOB. CAN GET THE AIRPLANE ON TARGET
NORMAL ACCELERATION CONTROL	PRETTY GOOD. CAN SNAP ON G QUICKLY, WITH LITTLE OVERSHOOT	BETTER THAN PITCH ATTITUDE. ONLY OVERSHOOTS SOME, PERHAPS 0.4 G	O.K. SMALL TENDENCY TO OVERSHOOT THE DESIRED G VALUE ON THE METER BUT NOT SO IN GENERAL MANEUVERING
EFFECTS OF RANDOM DISTURBANCES	NO PARTICULAR PROBLEM JUST EMPHASIZED PROBLEMS IN ATTITUDE CONTROL.	WOULD BE A BAD AIRPLANE IN TURBULENCE	NOTICEABLE, BUT NOT A PROBLEM
IFR PROBLEMS	PRETTY GOOD IFR. NONE OF VFR TRACKING PROBLEMS SEEM TO SHOW UP IFR.	NO PROBLEMS. PERFORMANCE ON TRACKING TASKS WAS GOOD	NOTHING NEW. BOBBLING TENDENCY SHOWED UP IN THE G.E TRACKING TASK
GOOD FEATURES	CAN MANEUVER AND PULL G ACCURATELY.	GOOD ON PULLING G.	GENERAL MANEUVERING CHARACTERISTICS AND CAPABILITIES ARE QUITE GOOD.
OBJECTIONABLE FEATURES	VERY DIFFICULT TO ACQUIRE TARGET. NOT TOO STEADY ON TARGET. STEADY FORCES QUITE HIGH. INITIAL FORCES LIGHT	PITCH ATTITUDE CONTROL VERY POOR. GET LARGE OVERSHOOT ACQUIRING A TARGET THEN OSCILLATE ABOUT TARGET. NOT STEADY ON TARGET. STEADY FORCES HIGH. STICK FORCE PER KNOT HIGH	BOBBLING TENDENCY WHEN TRYING TO STOP ON TARGET WHICH IN THE BEGINNING SEEMED BAD ENOUGH TO BE A PIO BUT RAPIDLY ADAPTED TO THIS CONFIGURATION TO THE EXTENT THAT THIS PROBLEM WAS NOT SERIOUS

NOTE (1) ALL FLOWN WITH POSITION COMMANDS

NOTE (2) F/N HIGH LIMITS INCORRECTLY SET.

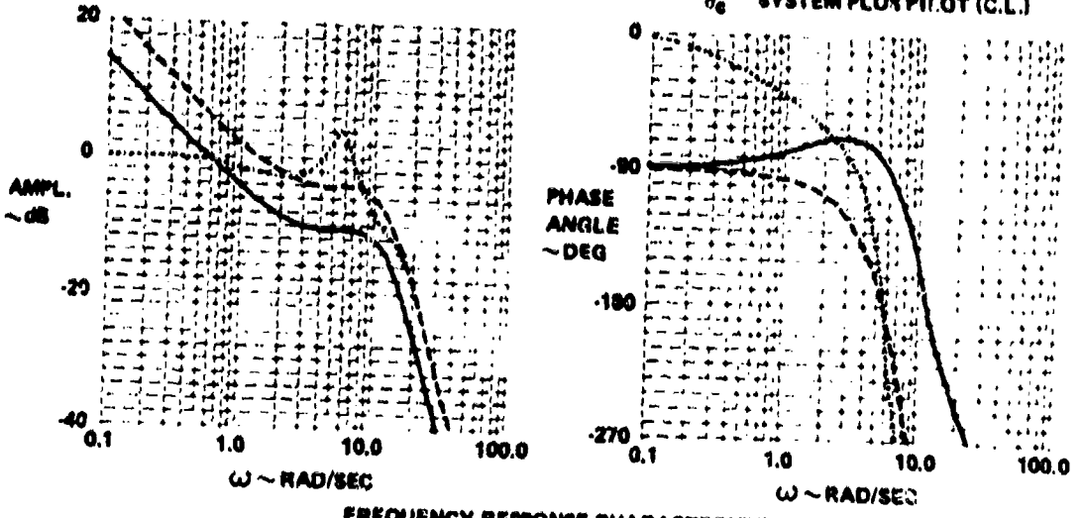
12

$1/T_{\theta_2}$ = 2.4	BW = 3.6
ω_{sp} = 5.0	Δ_{ps} = 0
V_T = 878	K_L = 1.23

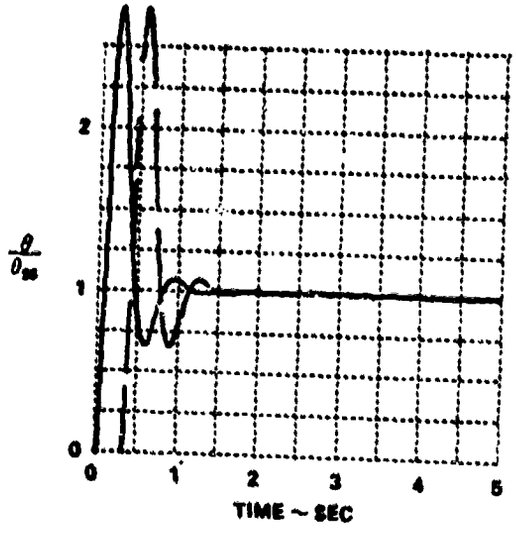
$\frac{\theta}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

$\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTHOL SYSTEM PLUS PILOT (O.L.)

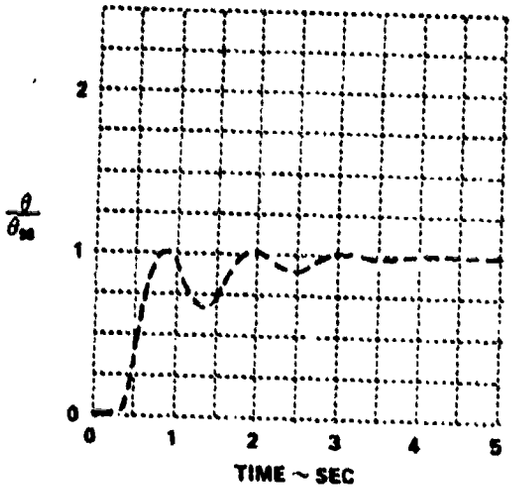
$\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_c IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

1	CONFIGURATION - 1 ω_{sp} = 1.3 ζ_{sp} = 0.34 - 7 - / 7L

PLT /PILOT	1053/M	1066 [2] / M
PR/PIOR	7/3	5.5/2.5
$(F_s/n)/K_{ij}$	60/46	31/34
K_p/K_{BW}	2.7/2.5	2.7/3.4
STICK FORCES	VERY DIFFICULT TO SELECT ALMOST HAVE TO DO FULL EVALUATION ON EACH GEAR ING TRIED IN ORDER TO SELECT ONE ENDED UP SELECTING SOMEWHAT HEAVY STEADY FORCES TO IMPROVE THE RATHER ABRUPT ATTI TUDE RESPONSE NO REAL SECOND THOUGHTS ON GEARING SELECTION	ON THE HEAVY SIDE HIGH STICK FORCE PER KNOT LEADS TO VERY HIGH MANEU VERING FORCES
PREDICTABILITY OF RESPONSE	NOT VERY GOOD AS FAR AS ATTITUDE RESPONSE IS CON CERNED NOSE VERY SELDOM GOES WHERE YOU WANT IT TO INITIAL AND STEADY FORCES SEEM COMPATIBLE	OVERSHOOTS TARGET BOBBLE BADLY ON TARGET - A REAL PROBLEM
ATTITUDE CONTROL - TRACKING CAPABILITY	IF YOU MOVE THE NOSE SMOOTHLY AS YOU MIGHT DO IFR THE ATTITUDE CON TROL IS PRETTY GOOD BUT FOR THE TIGHT ATT ITUDE CONTROL REQUIRED DURING VFR TRACKING IT'S A DIFFERENT AIRPLANE YOU JUST CAN'T TRACK AT ALL.	A PROBLEM - TEND TO OVERSHOOT TARGET AND BOBBLE AROUND IT QUITE HIGH FREQUENCY ONCE SETTLED DOWN IT'S RELA TIVELY STEADY ON TARGET NERVOUS AIRPLANE - SOMETHING I DON'T LIKE
NORMAL ACCELERATION CONTROL	NOT ALL THAT BAD. CAN PULL G PRETTY WELL	PRETTY GOOD. VERY SMALL OVERSHOOTS. IT FEELS NICE TO MANEUVER (EXCEPT FOR HIGH STEADY FORCES)
EFFECTS OF RANDOM DISTURBANCES	GREATLY EMPHASIZES TRACKING PROBLEMS	SHOWED UP SOMETHING CLOSE TO A PIO
IFR PROBLEMS	PRETTY GOOD AIRPLANE IFR - UNSATISFACTORY, BUT ADEQUATE	NO PROBLEMS HERE
GOOD FEATURES	PRETTY GOOD FOR GROSS MANEUVERING TRACKING CAPABILITY IS NOT TOO BAD IF YOU FLY IT VERY SMOOTHLY	GOOD FOR MANEUVERING ONCE ON TARGET IT'S NOT BAD CAN PULL SMALL INCREMENTAL G's QUICKLY AND PRECISELY
OBJECTIONABLE FEATURES	STEADY FORCES WERE ON HEAVY SIDE VERY DIFFI CULT TO ACQUIRE A TARGET RAPIDLY ESPECIALLY IN THE PRESENCE OF THE RN DISTURBANCES	TOO RESPONSIVE INITIALLY TEND TO OVERSHOOT WHEN YOU'RE ACQUIRING A TARGET AND BOBBLE QUITE A BIT BEFORE SETTLING DOWN STEADY FORCES TOO HEAVY

NOTE (1) ALL FLOWN WITH POSITION COMMANDS

NOTE (2) F/A HIGH LIMITS INCORRECTLY SET

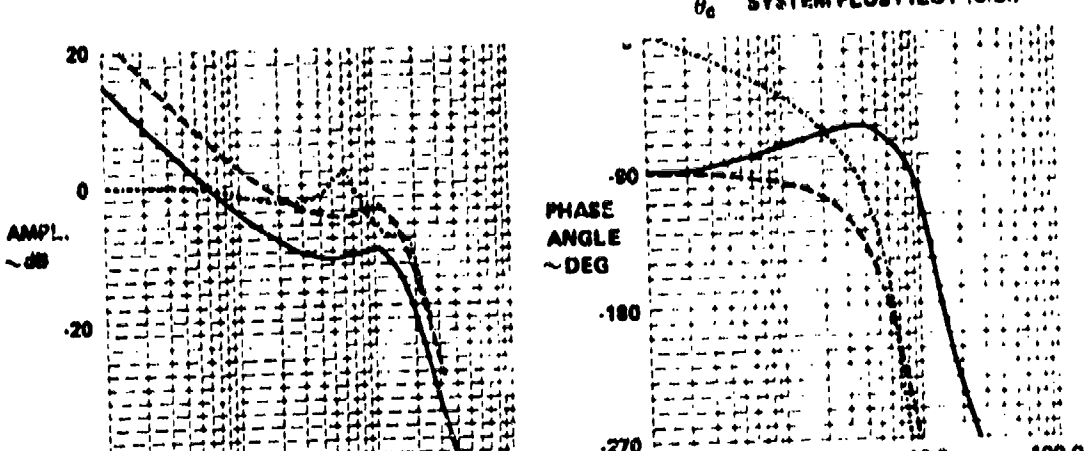
13

$1/T_{\theta_2}$ = 2.4	BW = 3.5
n/α = 50	Δ_{ps} = -6
V_T = 675	K_L = 1.25

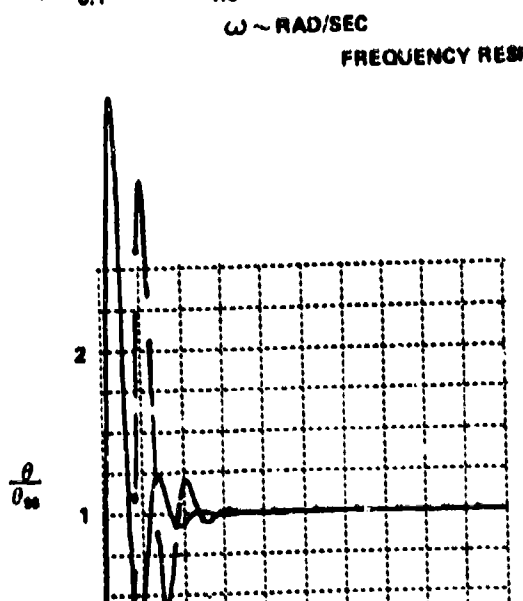
—— $\frac{\theta}{F_s}$ AIRPLANE PLUS CONTPOL SYSTEM (O.L.)

— — $\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

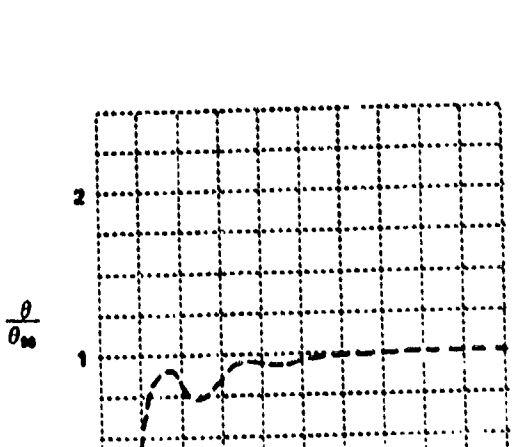
- - - - $\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

14	CONFIGURATION 11 ω_{sp} = 1.5 b ζ_{sp} = .23 / . / 75

PLT /PILOT	1052/M	1054 M
PR/PIOR	4 5/2	6/3
$(F_e/n)/K_{//}$	5 4/ 51	5 4/ 51
K_p/K_{BW}	2 6/2 3	2 6/2 3
STICK FORCES	STEADY FORCES ARE HEAVY INITIAL FORCES ARE LIGHT STEADY FORCES HEAVY SHOULD HAVE SELECTED LIGHTER FORCES, PERHAPS BUT NOT MUCH LIGHTER	STEADY FORCES ARE SOMEWHAT HEAVY BUT THIS GEARING HELPS THE TRACKING PROBLEM NO SECOND THOUGHTS ON GEARING SELECTION
PREDICTABILITY OF RESPONSE	GREAT FOR PULLING G BUT TENDS TO OSCILLATE IN PITCH	INITIAL FORCES ARE COMPATIBLE WITH STEADY FORCES THE PREDICTABILITY OF THE RESPONSE WAS NOT TOO GOOD
ATTITUDE CONTROL TRACKING CAPABILITY	DIFFICULT TO ACQUIRE TARGET NOT STEADY ON TARGET OVERSHOOTS AND OSCILLATES FAIRLY POOR	A REAL PROBLEM IN ACQUIRING A TARGET OSCILLATES ABOUT TARGET NOT STEADY ON TARGET EITHER
NORMAL ACCELERATION CONTROL	QUITE GOOD CAN QUICKLY AND ACCURATELY PULL G	PRETTY GOOD COULD PULL G QUICKLY AND ACCURATELY
EFFECTS OF RANDOM DISTURBANCES	NO NEW PROBLEMS	HAD SIGNIFICANT EFFECTS REALLY BRINGS OUT PIO TENDENCIES
IFR PROBLEMS	NO NEW PROBLEMS	NOT TOO BAD IFR
GOOD FEATURES	GOOD G CONTROL	NOT TOO BAD FOR PULLING G
OBJECTIONABLE FEATURES	DIFFICULT TO ACQUIRE TARGET AND NOT STEADY ON TARGET STEADY FORCES IN MANEUVERS ARE QUITE HEAVY INITIAL FORCES QUITE LIGHT	OSCILLATES WHEN ACQUIRING A TARGET NOT STEADY ON TARGET VERY BAD IN RN DISTURBANCES STEADY FORCES ARE SOMEWHAT HEAVY

NOTE 1) ALL FLOWN WITH POSITION COMMANDS

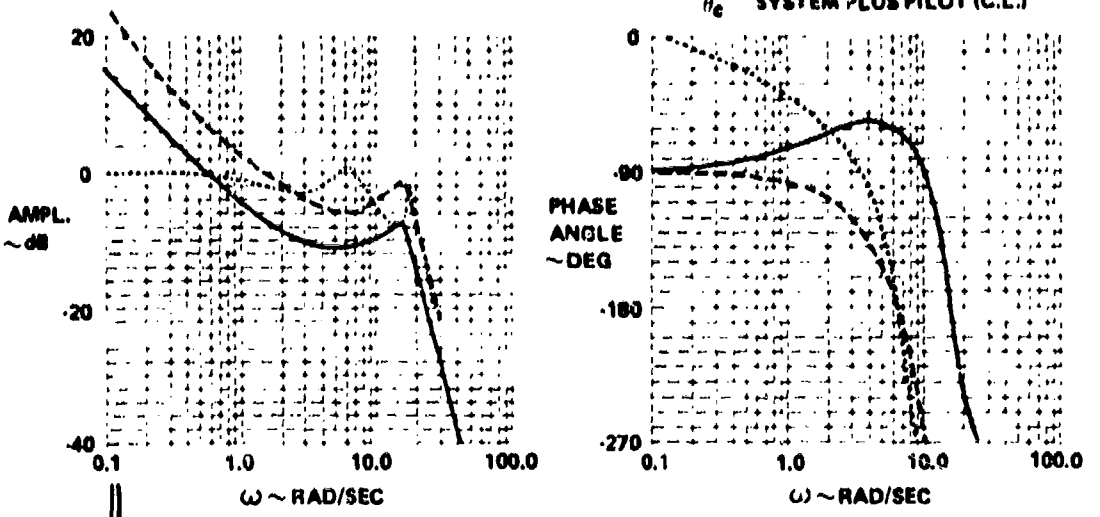
14

$1/T_{\theta_2}$	= 2.4	BW	= 3 r
n/α	= 50	Δ_{ms}	= -10
V_T	= 875	K_L	= 1.32

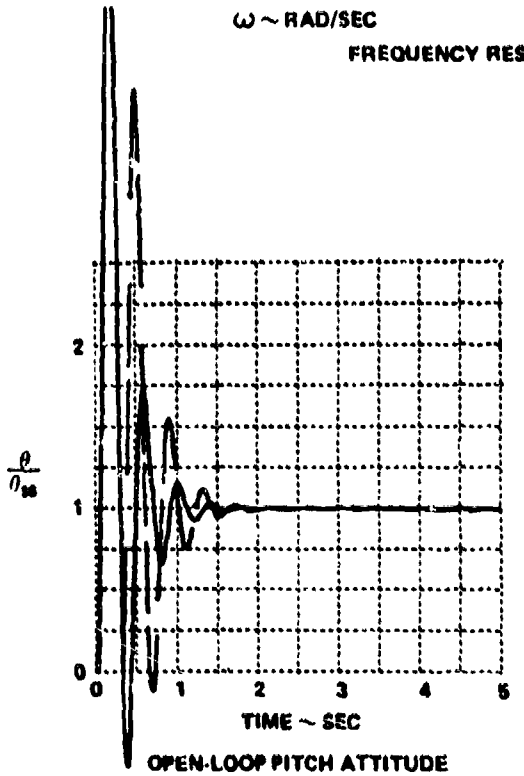
——— $\frac{n}{F_s}$ AIRPLANE PLUS CONTROL SYSTEM (O.L.)

— — — $\frac{\theta}{\theta_e}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (O.L.)

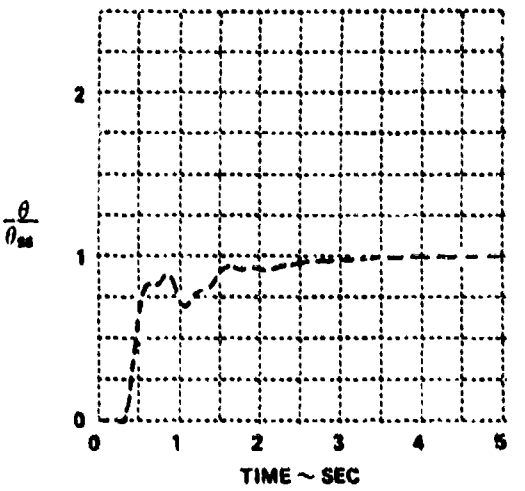
– – – – $\frac{\theta}{\theta_c}$ AIRPLANE PLUS CONTROL SYSTEM PLUS PILOT (C.L.)



FREQUENCY RESPONSE CHARACTERISTICS



OPEN-LOOP PITCH ATTITUDE RESPONSE TO AN F_s OR θ_e IMPULSE INPUT



CLOSED-LOOP PITCH ATTITUDE RESPONSE TO A STEP ATTITUDE COMMAND

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APPENDIX II

ANALYSIS OF DATA USING EQUIVALENT DYNAMICS

Early in the data analysis of the results of this experiment, it became evident that direct correlation of the pilot ratings with any of the modal parameters in the airplane-plus-control-system transfer functions was not possible. Accordingly, the equivalent system approach, used with some success in the HOS program (Reference 6), was applied to the basic FCS/short-period configurations of the present experiment.

For these basic configurations, the normalized $\dot{\theta}/F_s$ transfer function is:

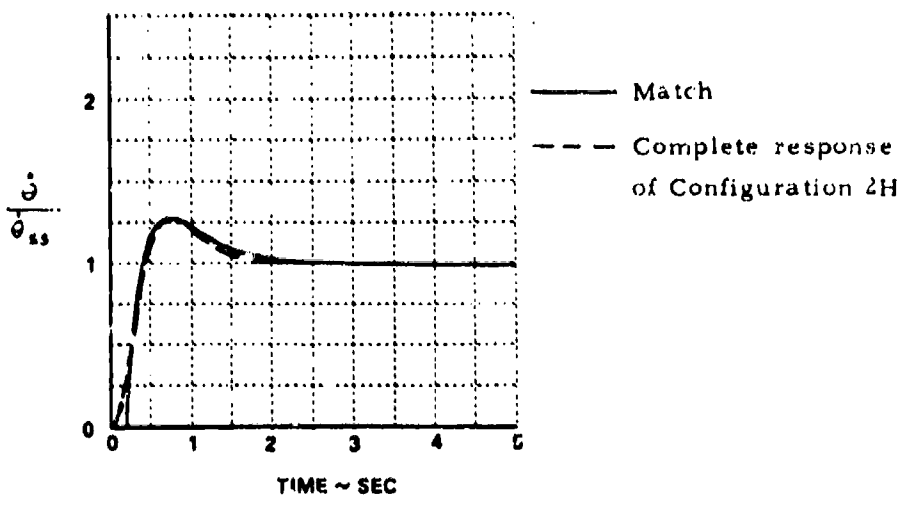
$$\left.\frac{\dot{\theta}}{F_s}\right|_{norm} = \frac{(\tau_{\theta_2}s+1)(\tau_1 s+1)}{\left(\frac{s^2}{\omega_{sp}^2}+\frac{2\zeta_{sp}}{\omega_{sp}}s+1\right)\left(\frac{s^2}{\omega_3^2}+\frac{2\zeta_3}{\omega_3}s+1\right)(\tau_4 s+1)}$$

In the equivalent system approach, the $\dot{\theta}$ step response of this transfer function is analog matched, as closely as possible, with the $\dot{\theta}$ response of a less complex, equivalent transfer function. The equivalent system has the form of an unaugmented airplane's transfer function plus a time delay:

$$\left.\frac{\dot{\theta}}{F_s}\right|_{norm} = e^{-a_E s}\,\frac{(\tau_E s+1)}{\left(\frac{s^2}{\omega_E^2}+\frac{2\zeta_E}{\omega_E}s+1\right)}$$

Both the complete and equivalent transfer functions were mechanized on an analog computer. The $\dot{\theta}$ step responses of the equivalent system were then matched to the complete $\dot{\theta}$ step responses of the airplane plus control system dynamics, by varying a_E, τ_E, ω_E and ζ_E until the best "eyeball" fit was obtained. In the majority of cases, τ_E was held fixed at the appropriate T-33 value of τ_{θ_2}. However, for those configurations with appreciable values of τ_1 (large control system lead), τ_E was also varied in order to achieve a reasonable match of the $\dot{\theta}$ time history.

The analog matches which were obtained with the equivalent transfer function were good for most of the configurations, with many showing near-perfect matches. For those configurations having large control-system lags, however, the match is somewhat poor for the initial portion of the response. For example, the following step time responses show the match used for Configuration 2H.



A summary of the equivalent system parameters, τ_e , T_{θ_e} , ω_e and ζ_e , obtained for each of the basic FCS/short-period configurations in this program is shown in the accompanying table, along with the pilot ratings. The pilot rating data for Pilot M and Pilot W are presented in Figures II-1 and II-2 on a plot of $\omega_e T_{\theta_e}$ versus τ_e . The correlation of the PR data plotted with these equivalent system parameters is reasonable and allows determination of the 3.5 and 6.5 pilot rating boundaries shown. The upper 6.5 pilot rating boundary is shown as a dashed line to reflect the fact that this part of the boundary is poorly substantiated. It is interesting to note that pilot ratings do not appear to be a function of equivalent time delay for $\tau_e < 0.1$ second.

It should be mentioned that the data for Configurations 4A through 5E are not shown on Figures II-1 and II-2. The reason for this is that the pilot ratings for these configurations are considerably worse than the values of $\omega_e T_{\theta_e}$ and τ_e would indicate. It is obvious, therefore, that the boundaries shown apply only for good values of ζ_e (say, $\zeta_e > 0.4$).

The pilot rating data from the HOS program for Pilot B and Pilot H are presented in Figures II-3 and II-4, for comparison with the PR boundaries established with the data from the present experiment. Again, only the data for good damping ($\zeta > 0.4$) are plotted. Note that because of the arrangement of the feel system dynamics in the control system of the HOS configurations, all the values of τ_e were greater than 0.1 seconds. The correlation of the PR data is only fair in some areas, but the same trends are shown for both programs.

DATA FOR EQUIVALENT SYSTEMS

CONFIG. NUMBER	τ_{α_e} ~ SEC	ω_{sp} ~ RAD/SEC	ζ_{sp}	τ_{α_e} ~ SEC	$\omega_{sp}\tau_{\alpha_e}$	PR PILOT M	PR PILOT M
1 A		2.4	.61	2.4	5.8	6, 4	5
B	.34	2.8	.74	0.88	2.8	3.5	3
C	.10	2.8	.75	1.03	2.9	3.5, 5	4
D	0	2.2	.69	.81	1.8	4.5, 5	3,4
E	.17	2.0	.60	.60	1.2	8	-
F	.25	1.5	.68	.81	1.2	8	8
G	.15	1.4	1.00	.81	1.1	8.5	8.5
2 A	.025	5.8	.52	1.00	5.8	4.5	4
B	.12	5.6	.52	1.02	6.0	6,4	4,5
C	.010	6.0	.66	.85	5.1	3	-
D	0	4.8	.70	.81	4.0	2.5, 3	2.5
E	.15	4.7	.68	.76	3.6	4	-
F	.15	3.8	.67	.73	2.8	3	-
G	.21	3.8	.70	.79	3.1	7	-
H	.21	3.2	1.00	.81	2.6	5,6	5.5
I	.25	3.0	.82	.68	2.0	8	8
J	.20	1.4	1.30	.81	1.1	6	6
3 A	0	9.7	.63	.81	7.8	4,5	4,4
B	.09	8.2	.67	.76	6.2	4.5	-
C	.10	6.9	.80	.73	5.1	4	3
D	.10	1.8	1.80	.81	1.5	4	4
E	.11	2.5	2.00	.81	1.8	4	4
6 A	.05	3.6	.64	1.38	5.0	5	6
B	.025	3.4	.70	0.57	2.2	1, 2.5	4
C	0	3.4	.67	0.42	1.4	4	5
D	.15	3.0	.67	0.42	1.3	5.5	-
E	.20	2.6	.76	0.42	1.1	8.5	7
F	.18	1.5	1.15	0.42	0.63	8	8.5, 10
7 A	.025	8.2	.61	.59	4.8	4,5	2
B	.025	8.2	.72	.45	4.1	3	-
C	0	7.8	.73	.42	3.1	3,3	1.5, 4
D	.08	6.4	.71	.47	3.0	5.5	-
E	.13	5.6	.65	.36	2.0	6	5
F	.11	5.1	.68	.22	1.1	3,4,4	7,7,7
G	.11	3.2	1.10	.42	1.3	5	6
H	.10	1.8	1.25	.42	.76	-	5
8 A	0	16.0	.69	.42	6.9	5	4
B	.10	14.0	.77	.44	6.2	3.5	-
C	.10	12.8	.83	.32	4.1	3.5	3
D	.10	9.6	1.00	.27	2.6	2	4
E	.06	2.7	1.65	.42	1.1	2.5, 3	5
4 A	0	5.0	.28	.81	4.0	5.5	5
B	.12	5.0	.28	.78	3.9	-	7
C	.25	5.1	.31	.63	3.2	8.5	-
D	.28	5.0	.36	.35	1.7	8,9	-
E		UNMATCHABLE				7.5	-
5 A	0	5.1	.18	.81	4.1	7	5,6
B	.10	5.2	.18	.79	4.1	-	7
C	.18	5.1	.19	.63	3.2	9	7
D	.25	5.1	.22	.30	1.5	8.5, 9	9
E		UNMATCHABLE				8	8

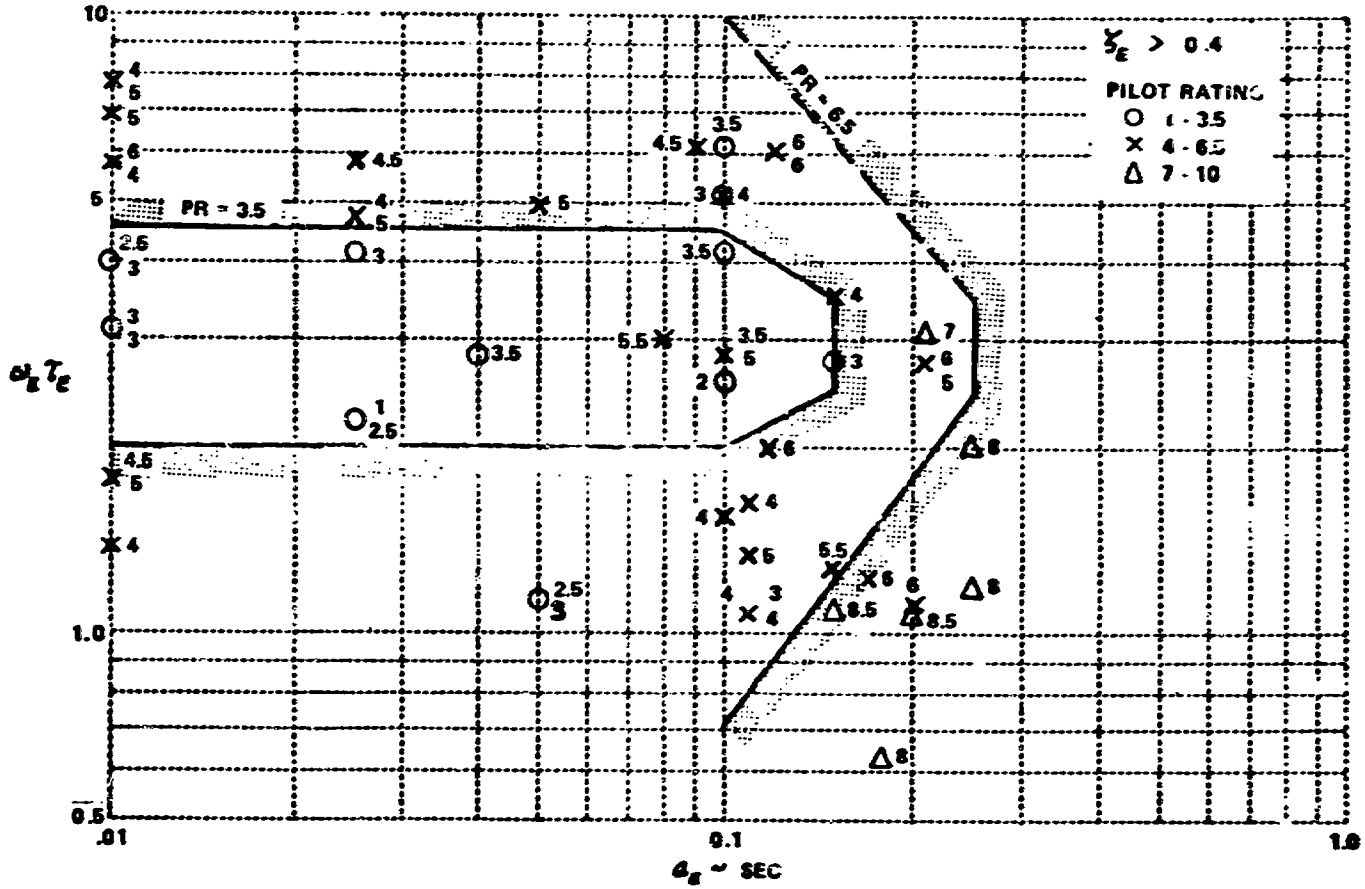


Figure II-1 Correlation of Pilot M Rating Data with Equivalent System Parameters

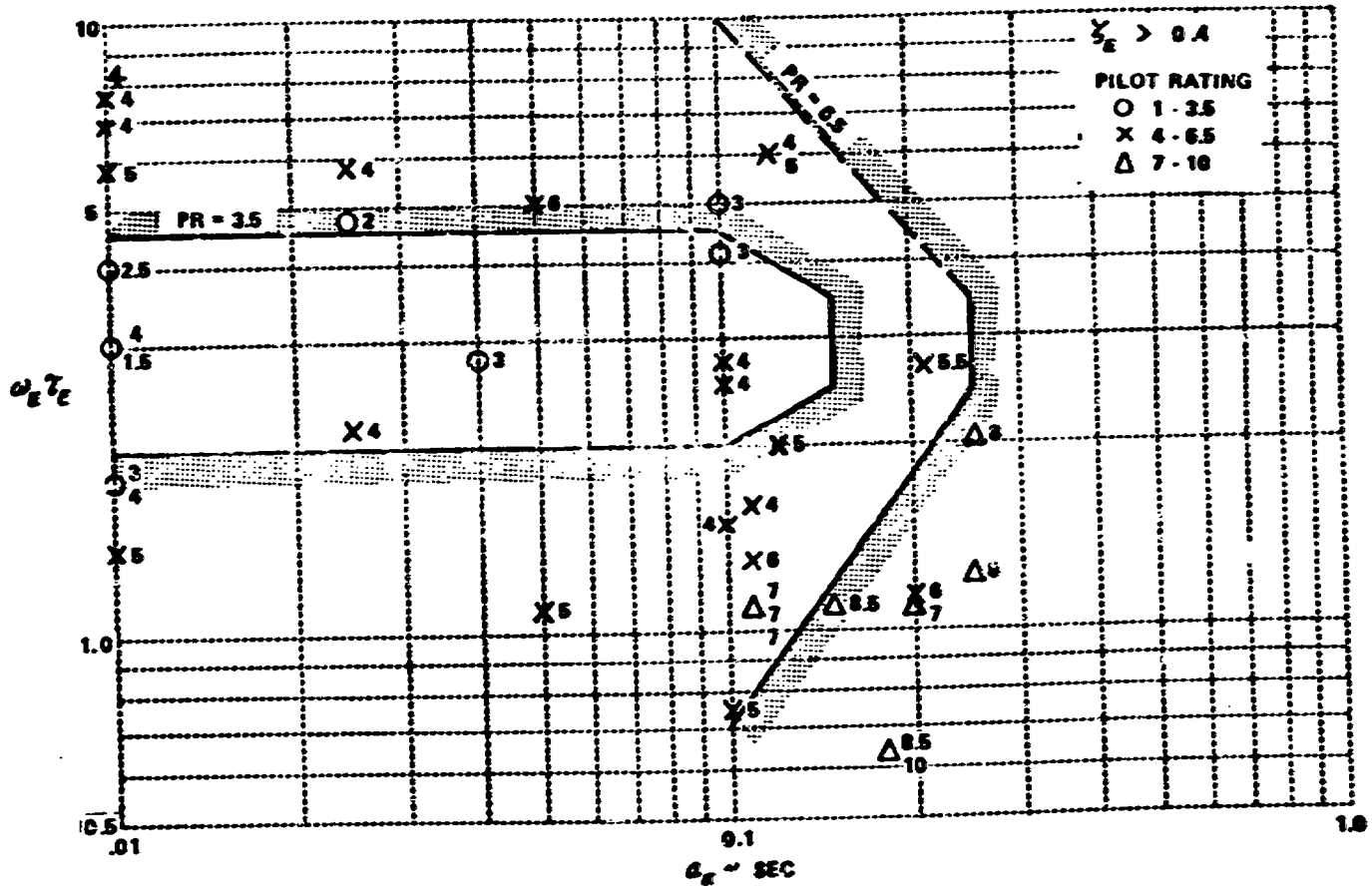


Figure II-2 Correlation of Pilot W Rating Data with Equivalent System Parameters

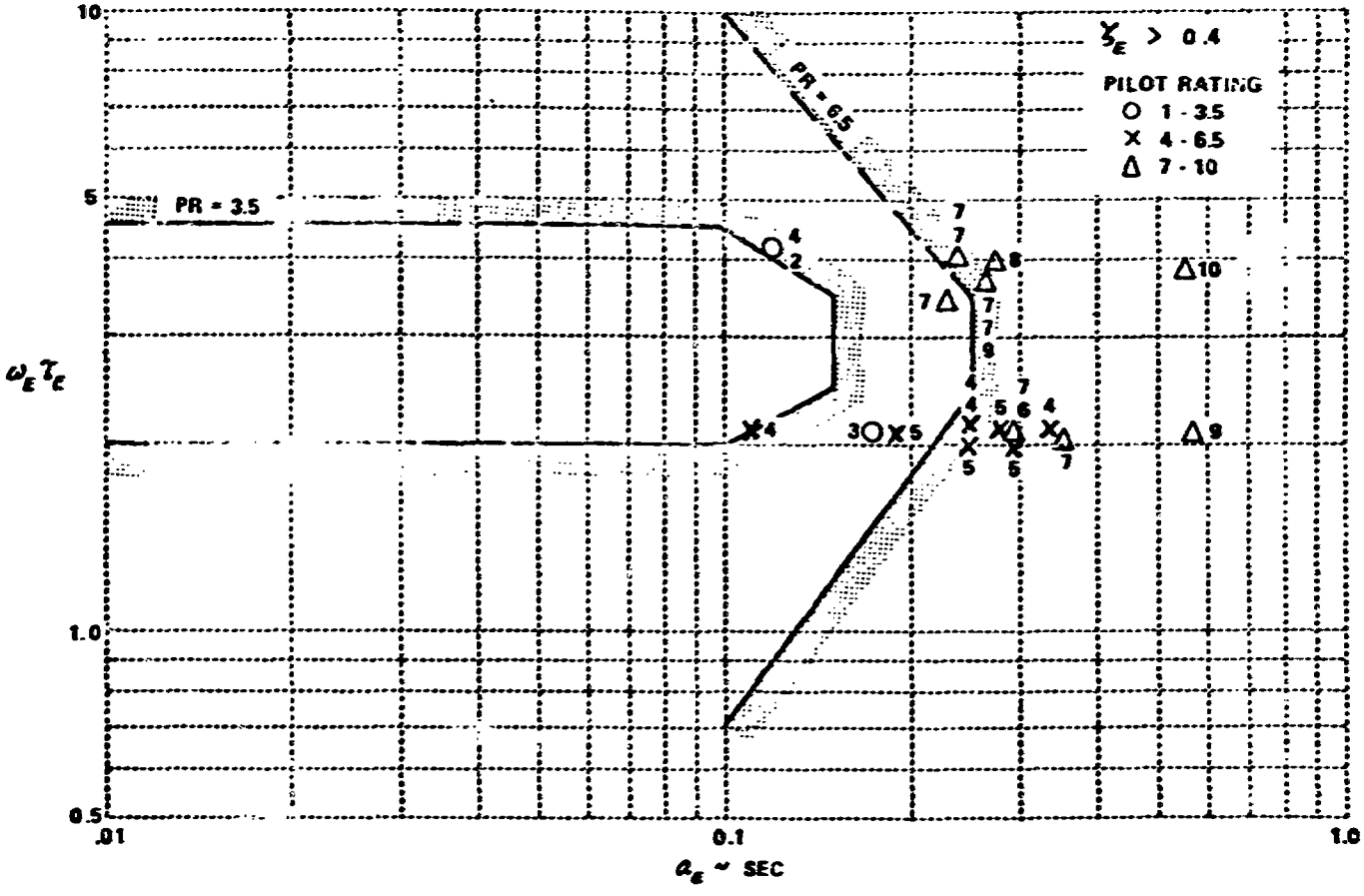


Figure II-3 Correlation of HOS Program Pilot B Rating Data (Reference 6) with Equivalent System Parameters

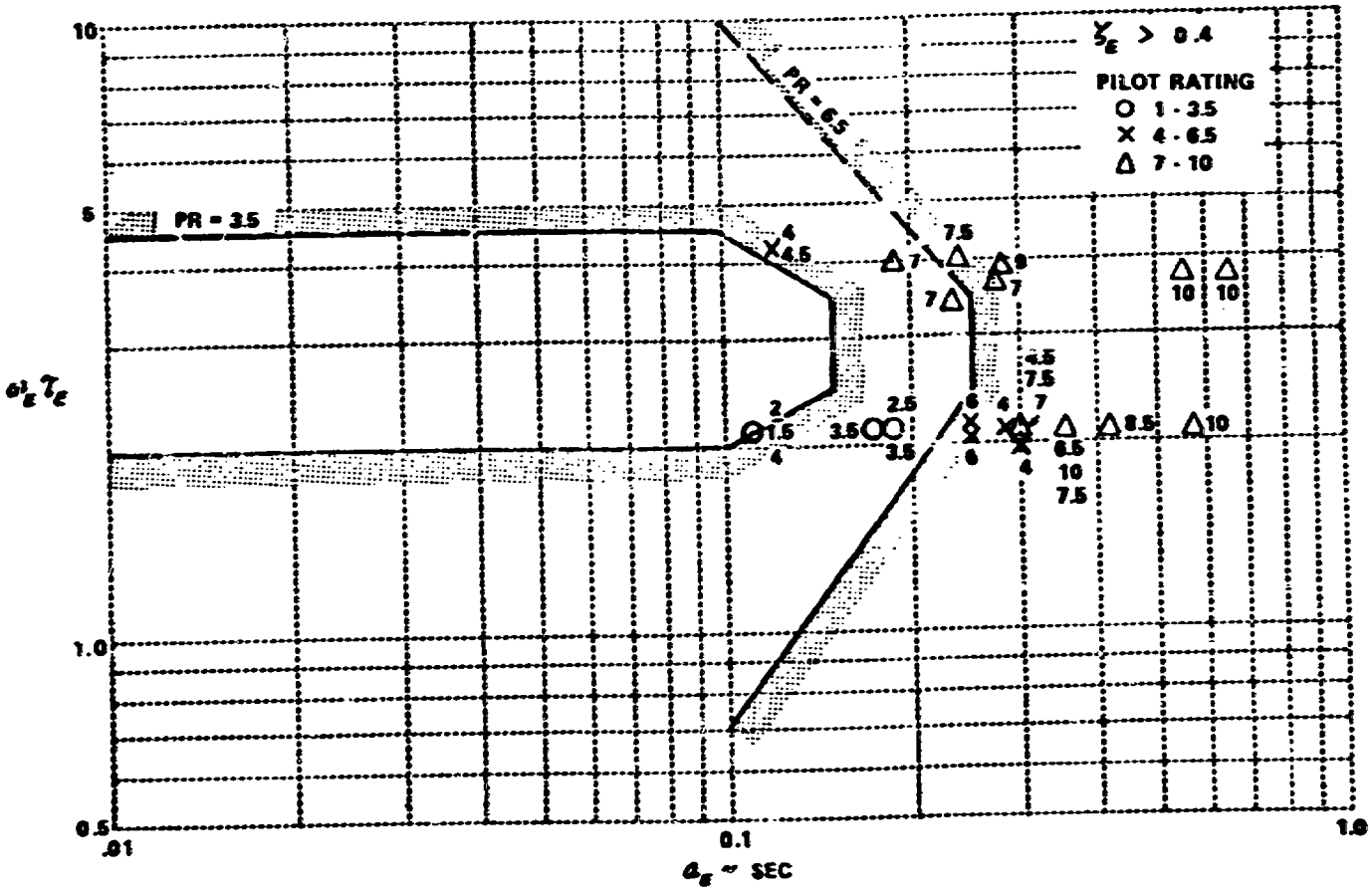
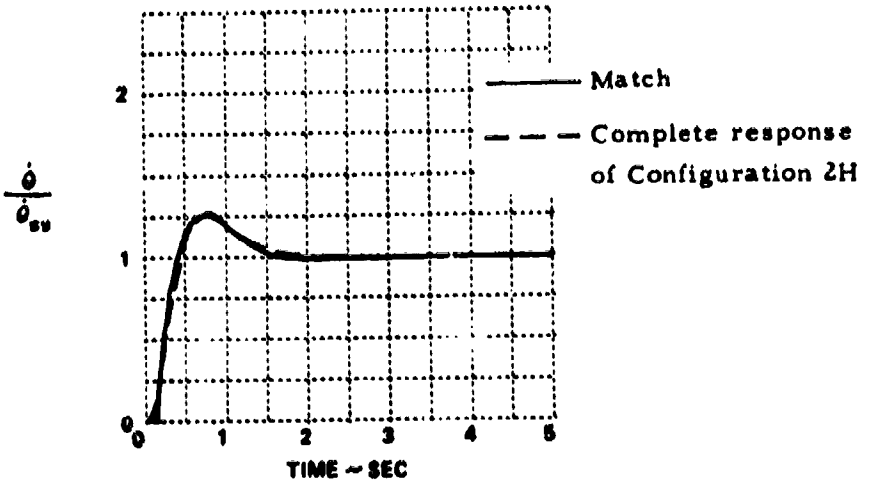


Figure II-4 Correlation of HOS Program Pilot H Rating Data (Reference 6) With Equivalent System Parameters

Thus, it would appear that the parameters $\omega_{\phi} \tau_{\phi}$ and a_{ϕ} tend to roughly group the data from the present experiment and the HOS program into iso-opinion regions, for configurations having good ζ_{sp}. There are two fundamental problems with this approach however. The first is the practical difficulty of measuring time delays as small as 0.1 sec. The second problem is the fact that when $\omega_{\phi} \tau_{\phi}$ is small, it can often be changed by factors of two or more and, with compensating changes in a_{ϕ}, τ_{ϕ} and ζ_{ϕ}, equally good analog matches can be obtained. For example, the above time history for Configuration 2H can be rematched with the following results.



Match	a_{ϕ}	ω_{ϕ}	ζ_{ϕ}	τ_{ϕ}	$\omega_{\phi} \tau_{\phi}$
Original	.21	3.2	1.00	.81	2.6
Rematch	.15	3.5	.70	.46	1.6

Thus, it is difficult to obtain a unique set of ω_{ϕ}, τ_{ϕ}, a_{ϕ}, and ζ_{ϕ} for a given configuration.

APPENDIX III

COMPLETE C* TIME HISTORIES

According to Reference 15, the C* response to a pilot force input is:

$$\frac{C^*}{F_s} = \frac{n}{F_s} + \frac{\ell_p}{g}\left(\frac{\ddot{\theta}}{F_s}\right) + \frac{400}{g}\left(\frac{\dot{\theta}}{F_s}\right)$$

$$= \frac{n}{F_s} + \left(\frac{\ell_p}{g}s + \frac{400}{g}\right)\left(\frac{\dot{\theta}}{F_s}\right)$$

where ℓ_p is the distance of the pilot's station ahead of the center of gravity, in feet. C^*/F_s and n/F_s have the units of g/lb, while $\dot{\theta}/F_s$ has the units of rad/sec per lb.

To conform to the manner in which the present simulation was mechanized (Appendix V), this can be expressed as:

$$\frac{C^*}{F_s} = \frac{\delta_e}{F_s}\left[\frac{C^*}{\delta_e}\right]$$

where δ_e/F_s is the transfer function of the simulated control system.
C^*/δ_e is the C* transfer function of the simulated airframe.

$$\therefore \quad \frac{C^*}{F_s} = \frac{\delta_e}{F_s}\left[\frac{n}{\delta_e} + \left(\frac{\ell_p}{g}s + \frac{400}{g}\right)\frac{\dot{\theta}}{\delta_e}\right]$$

For the simulated control system:

$$\frac{\delta_e}{F_s} = \frac{\left(\frac{\delta_e}{F_s}\right)_{ss}(\tau_1 s + 1)}{(\tau_2 s + 1)\left(\frac{s^2}{\omega_s^2} + \frac{2\zeta_s}{\omega_s}s + 1\right)}$$

For the simulated airframe (see Appendix IV

$$\frac{n}{\delta_e} = \frac{M_{\delta_e}}{\omega_{sp}^2}\,\frac{\left(\frac{V_T}{g}\,\frac{1}{\tau_{\theta_2}}\right)\left[\left(\tau_{\theta_2} \cdot \frac{L_{\delta_e}}{M_{\delta_e}}\right)s^2 + 1\right]}{\left(\frac{s^2}{\omega_{sp}^2} + \frac{2\zeta_{sp}}{\omega_{sp}}s + 1\right)}$$

and

$$\frac{\dot{Q}}{\delta_e} = \frac{M_{\delta_e}}{\omega_{sp}^2} \frac{\left(\frac{1}{\tau_{\theta_2}}\right)(\tau_{\theta_2} s + 1)}{\left(\frac{s^2}{\omega_{sp}^2} + \frac{2\zeta_{sp}}{\omega_{sp}} s + 1\right)}$$

Substituting, and normalizing with respect to the steady state, yields:

$$\frac{C^*}{C^*_{ss}} = \frac{C^*}{F_s}\bigg|_{norm} = \frac{\left[\tau_{\theta_2}\left(\frac{\ell_p + \frac{V_T L_{\delta_e}}{M_{\delta_e}}}{V_T + 400}\right)s^2 + \left(\frac{\ell_p + 400\tau_{\theta_2}}{V_T + 400}\right)s + 1\right](\tau_1 s + 1)}{\left(\frac{s^2}{\omega_{sp}^2} + \frac{2\zeta_{sp}}{\omega_{sp}} s + 1\right)\left(\frac{s^2}{\omega_3^2} + \frac{2\zeta_3}{\omega_3} s + 1\right)(\tau_3 s + 1)}$$

For the T-33: $\ell_p = 7$ ft, $V_T L_{\delta_e}/M_{\delta_e} = -3$ ft

V_{ind}	= 250 knots:	V_T	= 480 ft/sec
		τ_{θ_2}	= 0.80 sec
V_{ind}	= 350 knots:	V_T	= 675 ft/sec
		τ_{θ_2}	= 0.42 sec

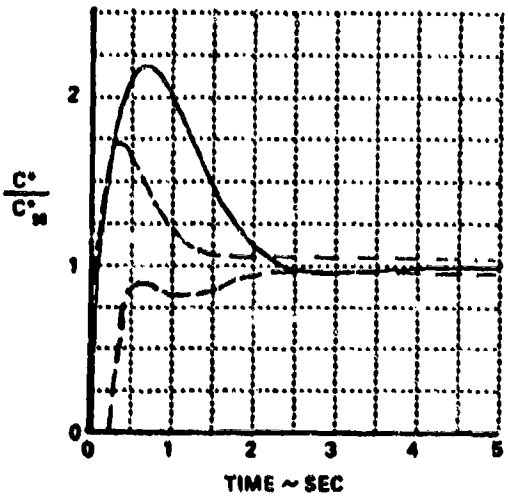
The C^* numerators become:

V_{ind}	= 250 knots:	$(.36s + 1)\ (.0103s + 1)\ (\tau_1 s + 1)$
V_{ind}	= 350 knots:	$(.15s + 1)\ (.0102s + 1)\ (\tau_1 s + 1)$

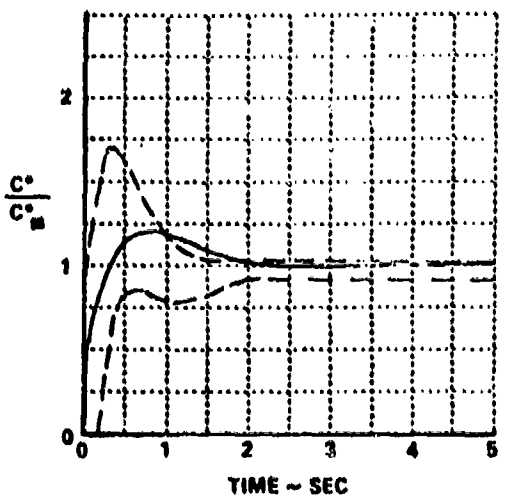
The normalized C* response to a step force input was calculated for each of the configurations evaluated in this experiment. These responses and their associated pilot ratings were then compared with the C* time-history boundaries of Reference 15 and the results are shown in the plots which follow.

C* TIME HISTORIES

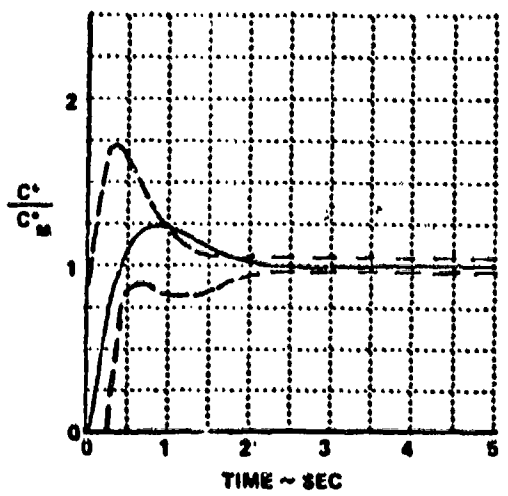
--- C* BOUNDARIES (PR = 3.5)



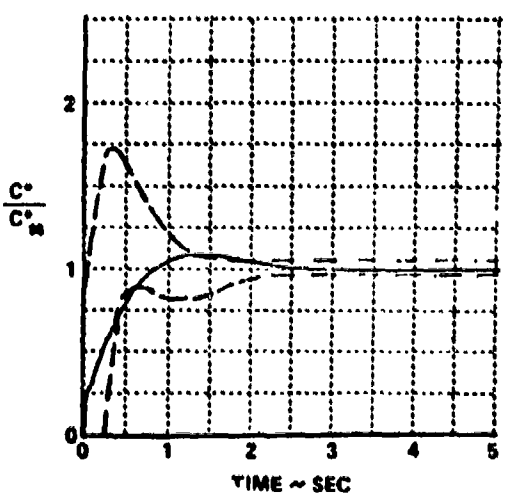
CONFIGURATION No. 1A PR(PILOT M): 6, 4
PR(PILOT W): 5



CONFIGURATION No. 1B PR(PILOT M): 3.5
PR(PILOT W): 3



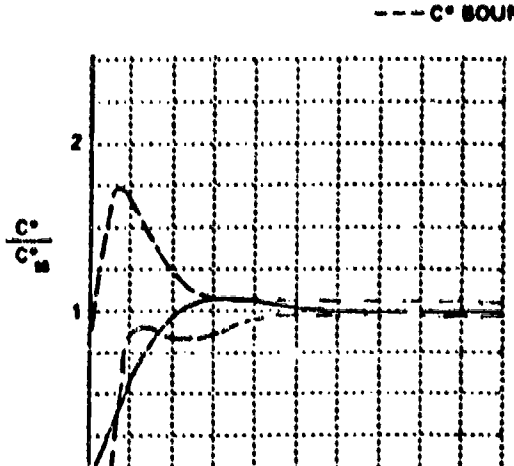
CONFIGURATION No. 1C PR(PILOT M): 5, 3.5
PR(PILOT W): 4



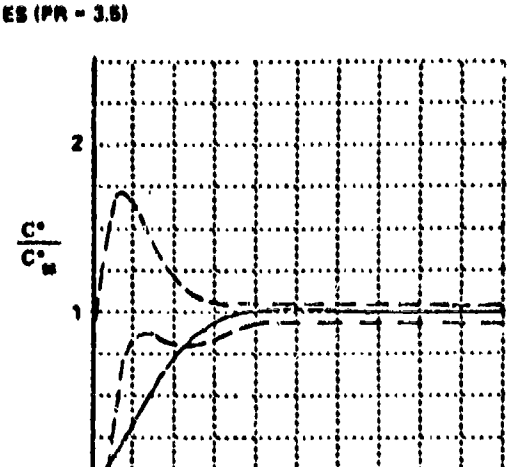
CONFIGURATION No. 1D PR(PILOT M): 5, 4.5
PR(PILOT W): 3, 4

C* TIME HISTORIES

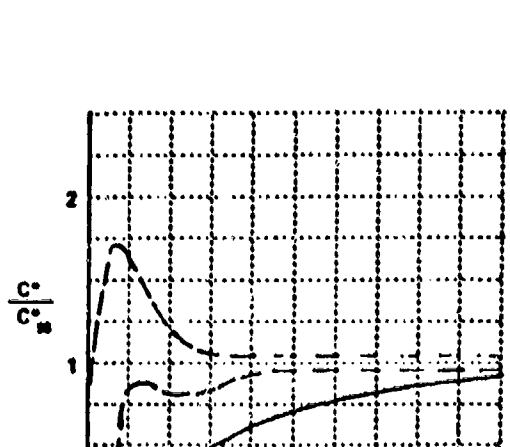
– – – C* BOUNDARIES (PR = 3.5)



CONFIGURATION No. 1E PR(PILOT M): 6
PR(PILOT W):



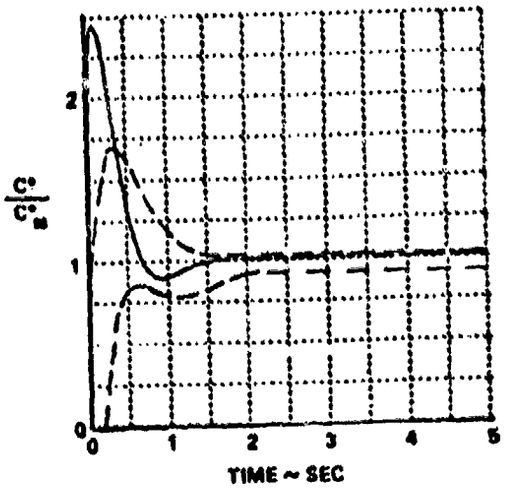
CONFIGURATION No. 1F PR(PILOT M): 6
PR(PILOT W): 6



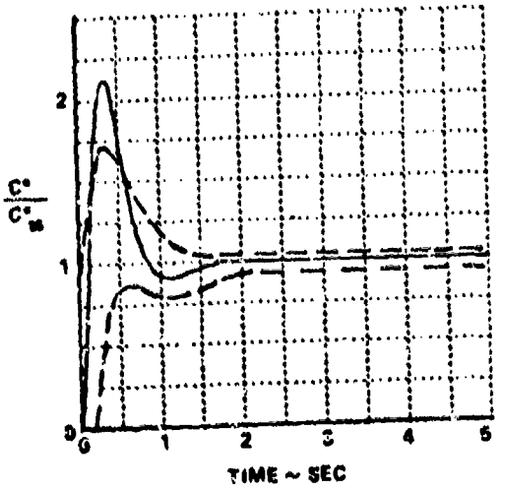
CONFIGURATION No 1G PR(PILOT M): 8.5
PR(PILOT W): 3.5

C* TIME HISTORIES

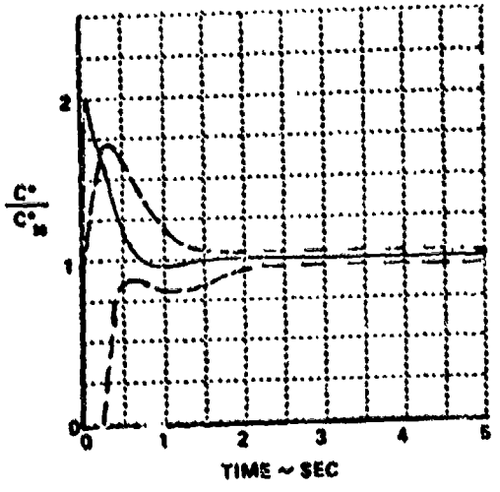
---- C* BOUNDARIES (PR = 3.5)



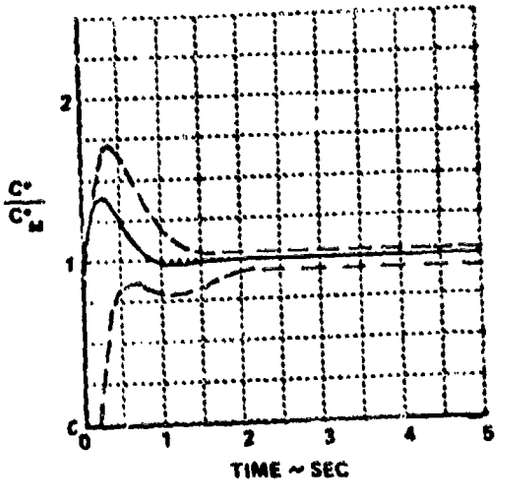
CONFIGURATION No. 2A PR(PILOT M): 4.5
PR(PILOT W): 4



CONFIGURATION No. 2B PR(PILOT M): 6, 6
PR(PILOT W): 4, 5



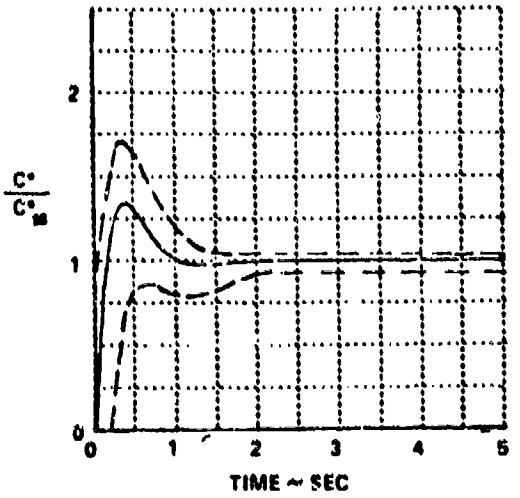
CONFIGURATION No. 2C PR(PILOT M): 3
PR(PILOT W):



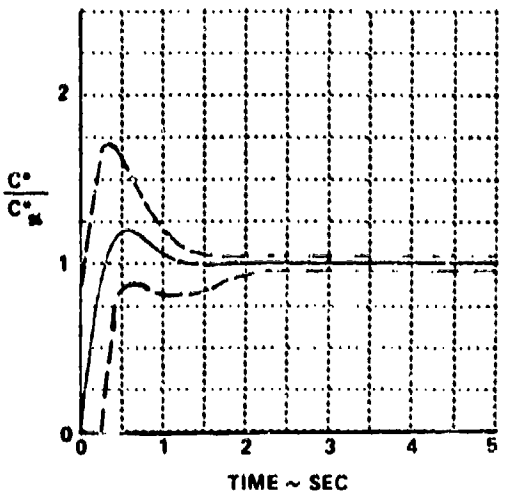
CONFIGURATION No. 2D PR(PILOT M): 3, 2.5
PR(PILOT W): 2.5

C* TIME HISTORIES

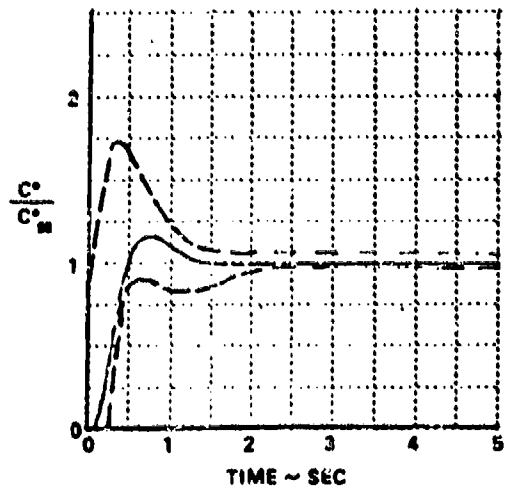
– – – C* BOUNDARIES (PR = 3.5)



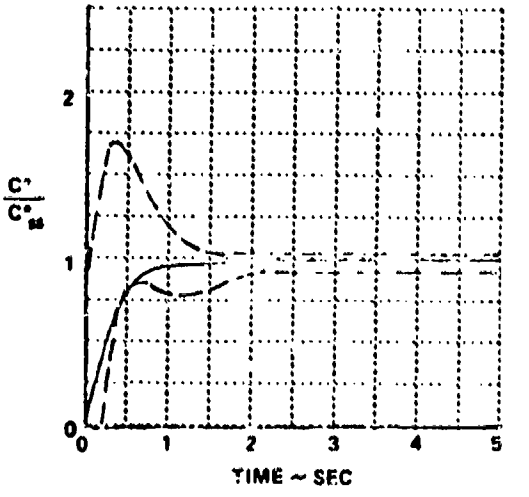
CONFIGURATION No. 2E PR(PILOT M): 4
PR(PILOT W):



CONFIGURATION No. 2F PR(PILOT M): 3
PR(PILOT W):



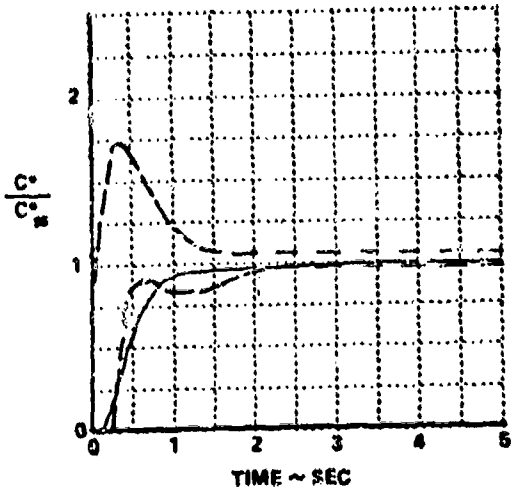
CONFIGURATION No. 2G PR(PILOT M): 7
PR(PILOT W):



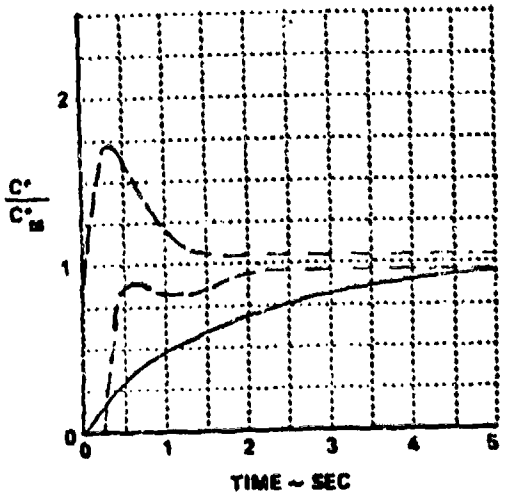
CONFIGURATION No. 2H PR(PILOT M): 5, 6
PR(PILOT W): 5.5

C* TIME HISTORIES

--- C* BOUNDARIES (PR = 3.5)



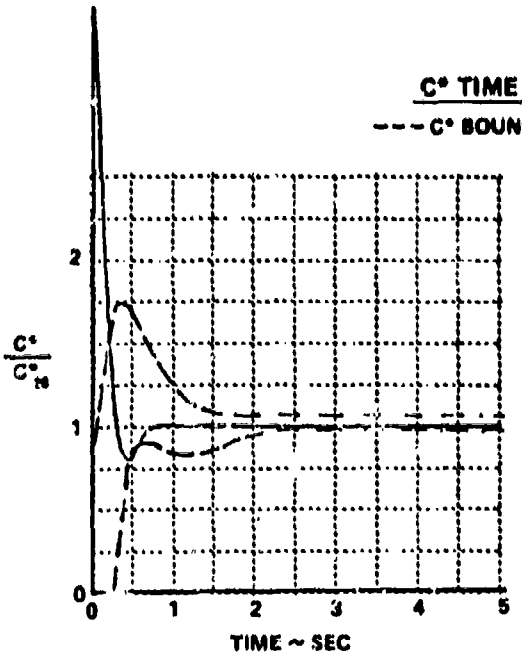
CONFIGURATION No. 21 PR(PILOT M): 8
PR(PILOT W): 8



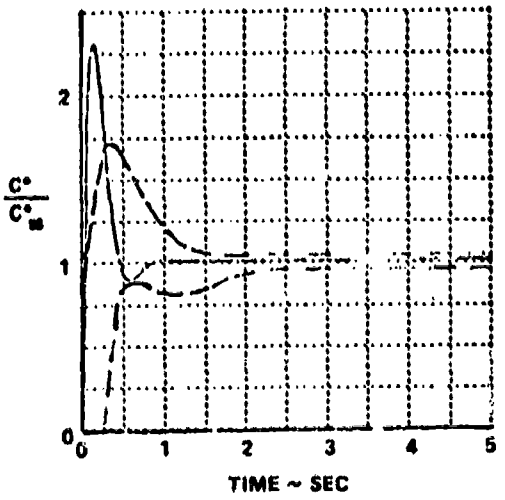
CONFIGURATION No. 23 PR(PILOT M): 6
PR(PILOT W): 6

C* TIME HISTORIES

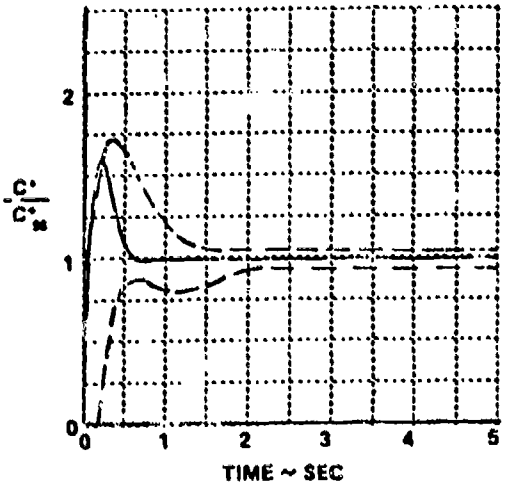
– – – C* BOUNDARIES (PR = 3.5)



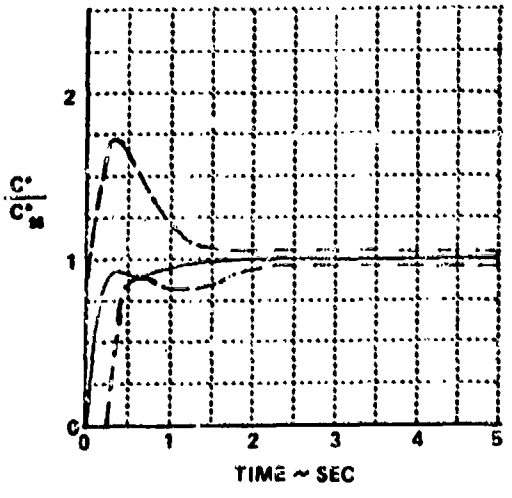
CONFIGURATION No. 3A PR(PILOT M): 5, 4
PR(PILOT W): 4, 4



CONFIGURATION No. 3B PR(PILOT M): 4.5
PR(PILOT W):



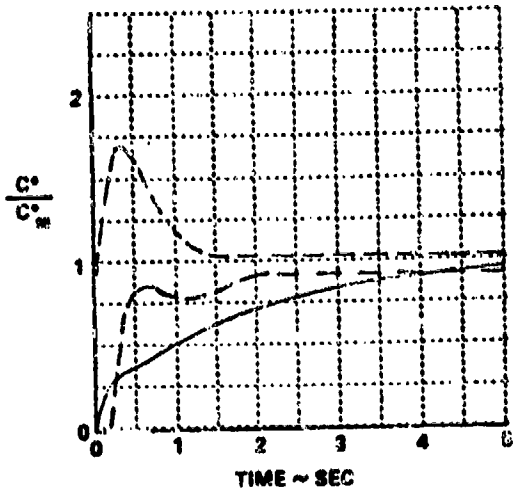
CONFIGURATION No. 3C PR(PILOT M): 4
PR(PILOT W): 3



CONFIGURATION No. 3D PR(PILOT M): 4
PR(PILOT W): 4

C* TIME HISTORIES

---- C* BOUNDARIES (PR = 3.5)



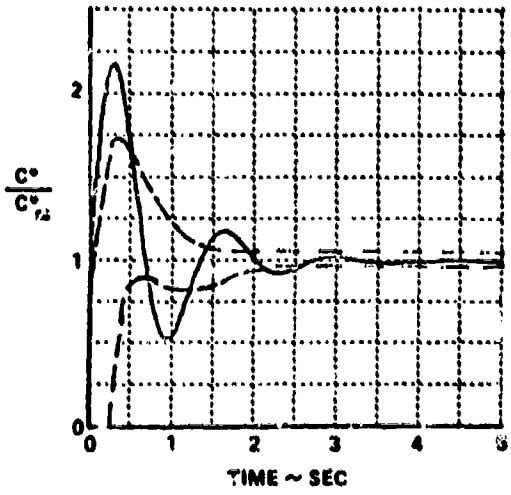
CONFIGURATION No. 3E

PR(PILOT M): 4

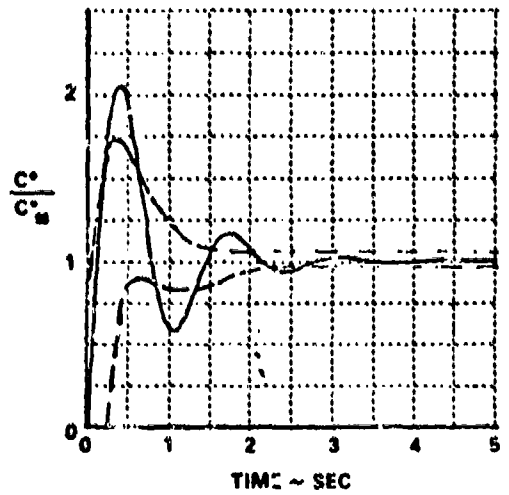
PR(PILOT W): 4

C* TIME HISTORIES

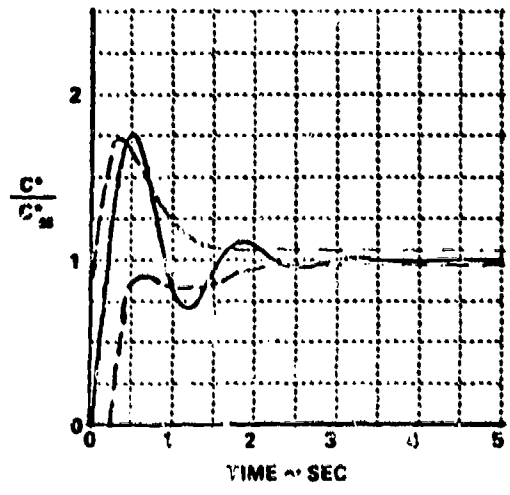
– – – C* BOUNDARIES (PR = 3.5)



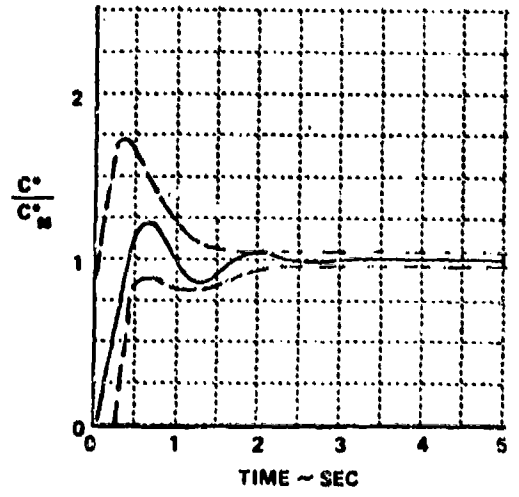
CONFIGURATION No. 4A PR(PILOT M): 5.5
PR(PILOT W): 5



CONFIGURATION No. 4B PR(PILOT M):
PR(PILOT W): 7



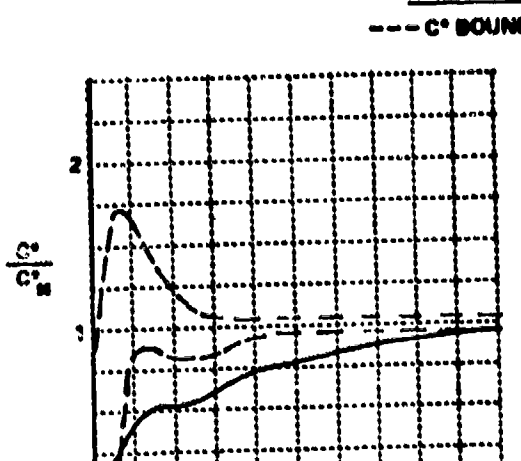
CONFIGURATION No. 4C PR(PILOT M): 8.5
PR(PILOT W):



CONFIGURATION No. 4D PR(PILOT M): 8, 9
PR(PILOT W):

C* TIME HISTORIES

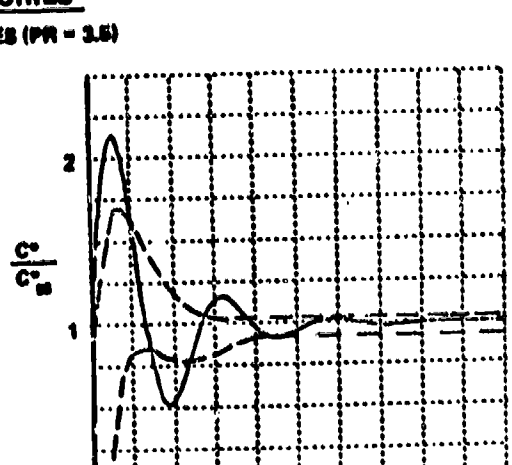
--- C* BOUNDARIES (PR = 3.5)



CONFIGURATION No. 4E

PR(PILOT M): 7.5

PR(PILOT W):



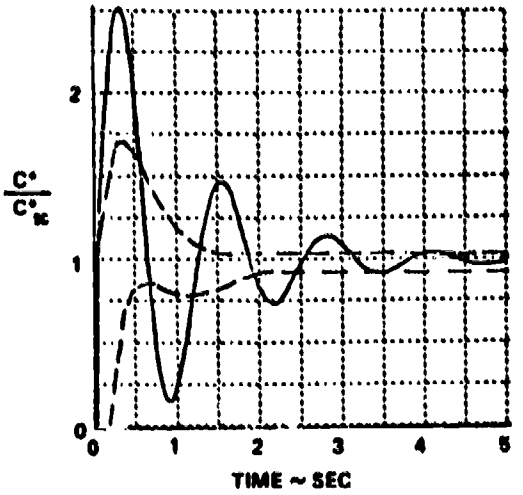
CONFIGURATION No. 4F

PR(PILOT M):

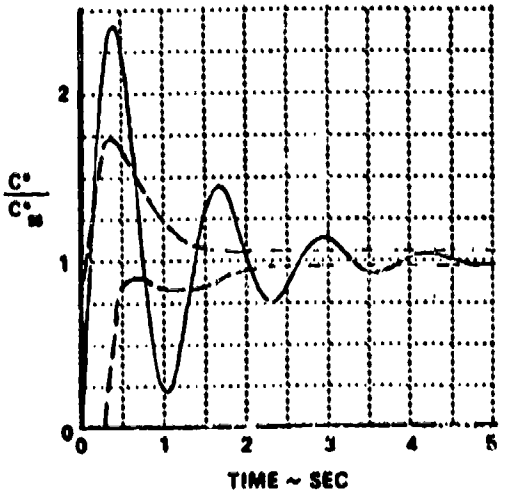
PR(PILOT W): 7

C* TIME HISTORIES

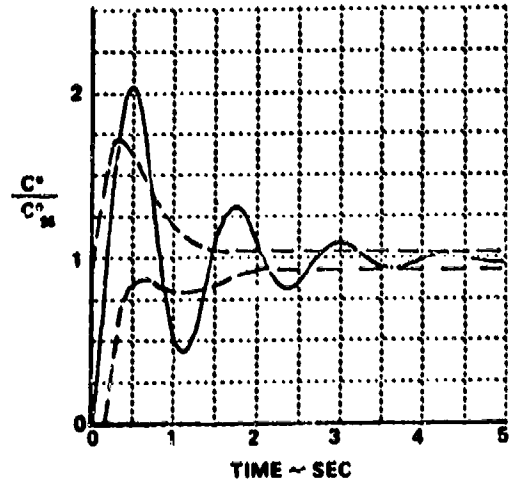
---C* BOUNDARIES (PR = 3.5)



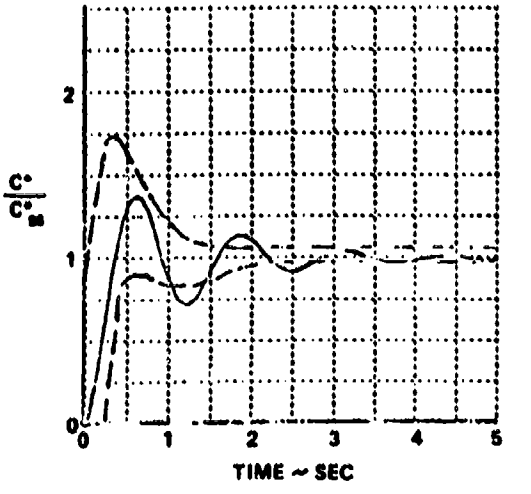
CONFIGURATION No. 5A PR(PILOT M): 7
PR(PILOT W): 5, 6



CONFIGURATION No. 5B PR(PILOT M):
PR(PILOT W): 7



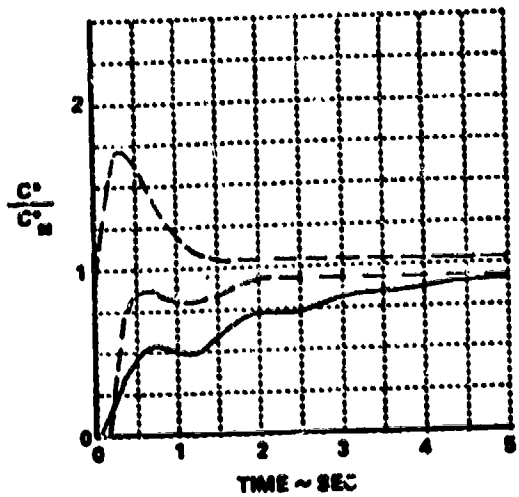
CONFIGURATION No. 5C PR(PILOT M): 9
PR(PILOT W): 7



CONFIGURATION No. 5D PR(PILOT M): 8.5, 9
PR(PILOT W): 9

C^* TIME HISTORIES

– – – C^* BOUNDARIES (PR = 3.5)



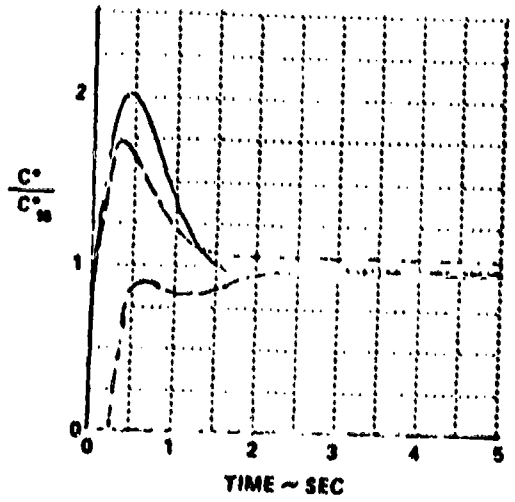
CONFIGURATION No. 5E

PR(PILOT M): 8

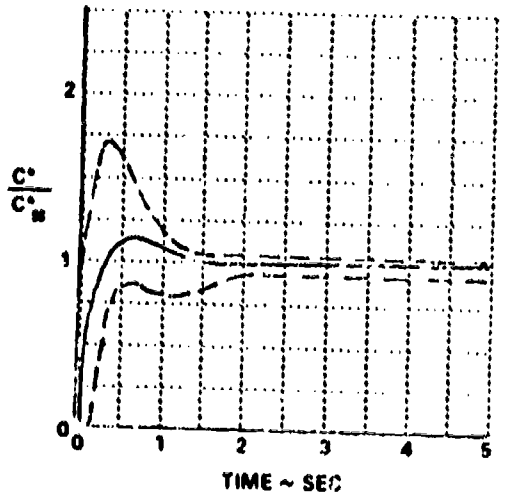
PR(PILOT W): 8

C* TIME HISTORIES

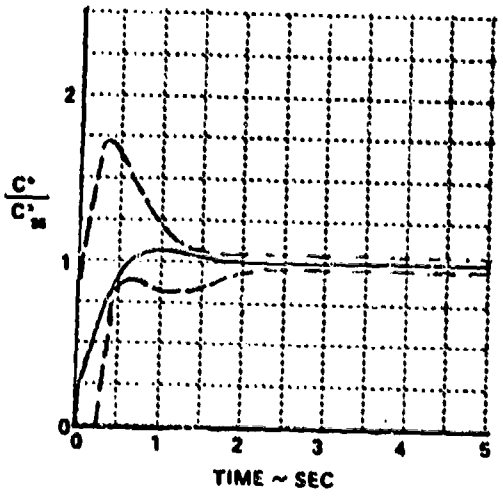
--- C* BOUNDARIES (PR = 3.5)



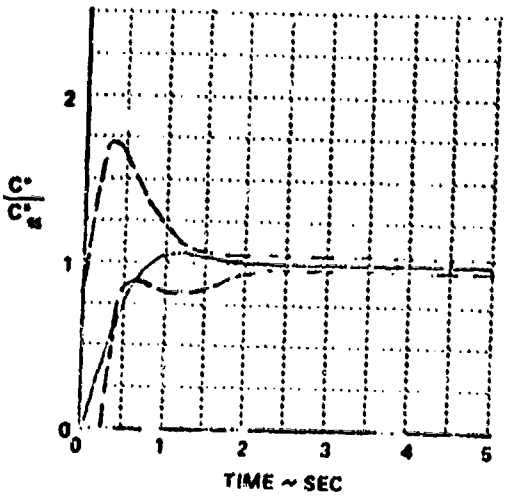
CONFIGURATION No. 6A PR(PILOT M): 5
PR(PILOT W): 6



CONFIGURATION No. 6B PR(PILOT M): 2.5, 1
PR(PILOT W): 4



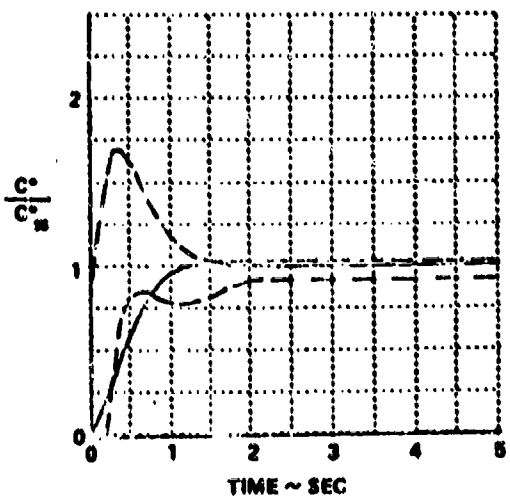
CONFIGURATION No. 6C PR(PILOT M): 4
PR(PILOT W): 5



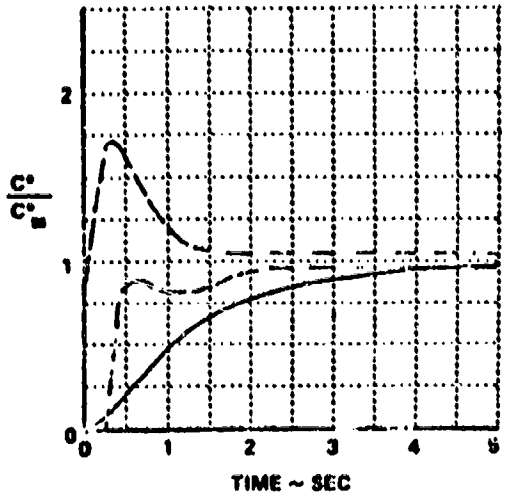
CONFIGURATION No. 6D PR(PILOT M): 5.5
PR(PILOT W):

C* TIME HISTORIES

– – – C* BOUNDARIES (PR = 3.5)



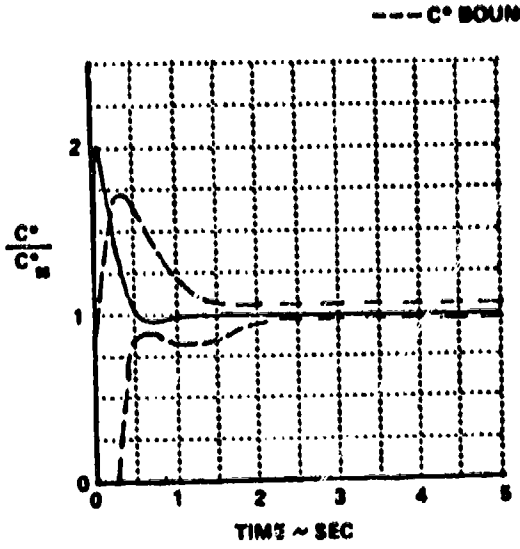
CONFIGURATION No. 6E PR(PILOT M): 8.5
PR(PILOT W): 7



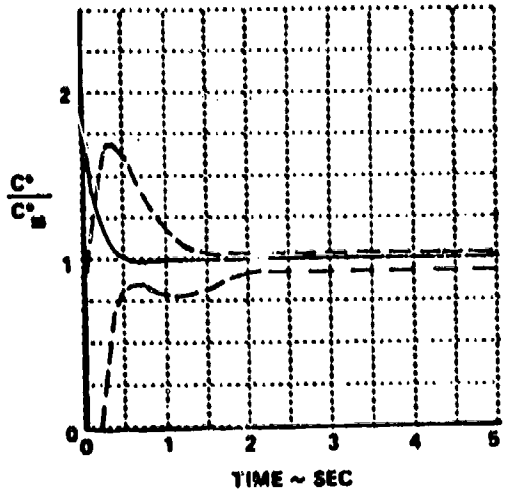
CONFIGURATION No. 6F PR(PILOT M): 8
PR(PILOT W): 8.5, 10

C* TIME HISTORIES

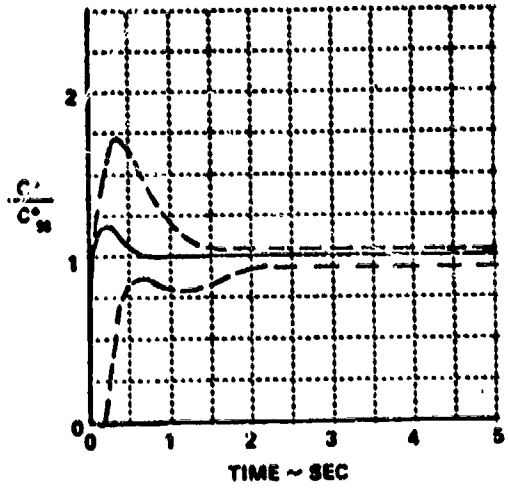
---C* BOUNDARIES (PR = 3.5)



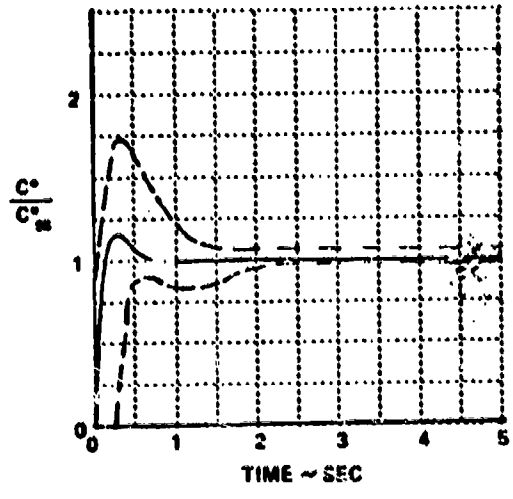
CONFIGURATION No. 7A PR(PILOT M): 5, 4
PR(PILOT W): 2



CONFIGURATION No. 7B PR(PILOT M): 3
PR(PILOT W):



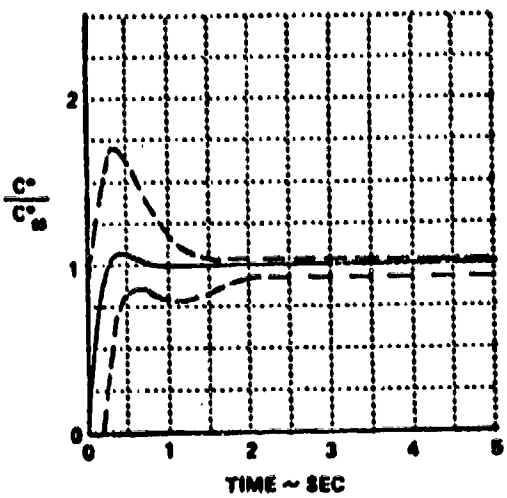
CONFIGURATION No. 7C PR(PILOT M): 3, 3
PR(PILOT W): 4, 1.5



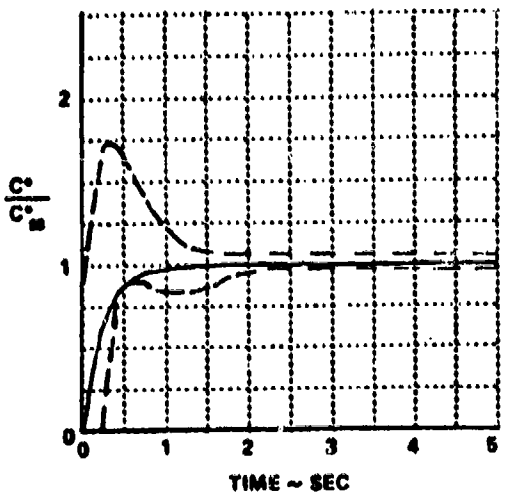
CONFIGURATION No. 7D PR(PILOT M): 5.5
PR(PILOT W):

C* TIME HISTORIES

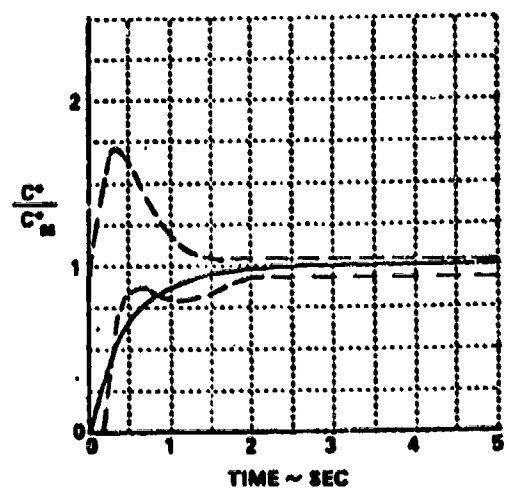
---C* BOUNDARIES (PR = 3.5)



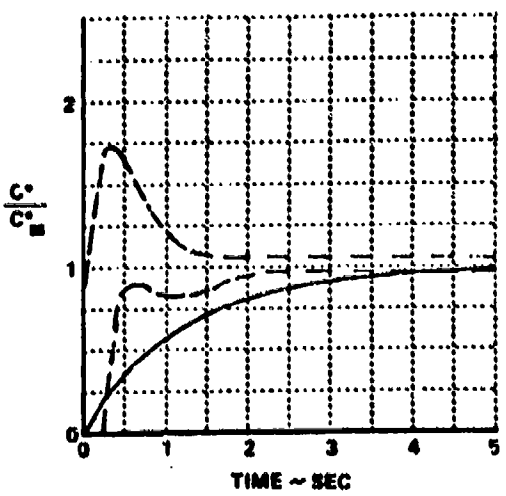
CONFIGURATION No. 7E PR(PILOT M): 6
PR(PILOT W): 6



CONFIGURATION No. 7F PR(PILOT M): 3, 4, 4
PR(PILOT W): 7, 7, 7



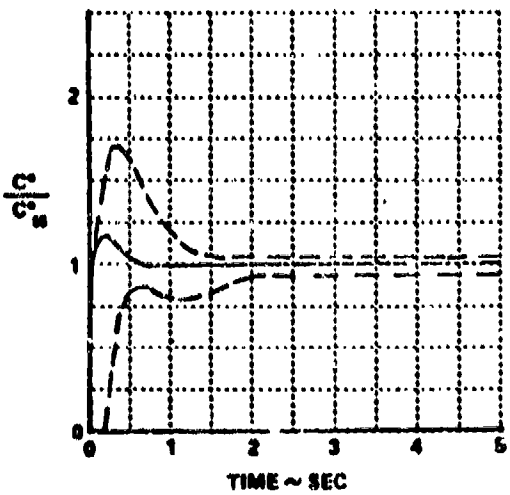
CONFIGURATION No. 7G PR(PILOT M): 5
PR(PILOT W): 6



CONFIGURATION No. 7H PR(PILOT M):
PR(PILOT W): 5

C* TIME HISTORIES

---C* BOUNDARIES (PR = 3.5)



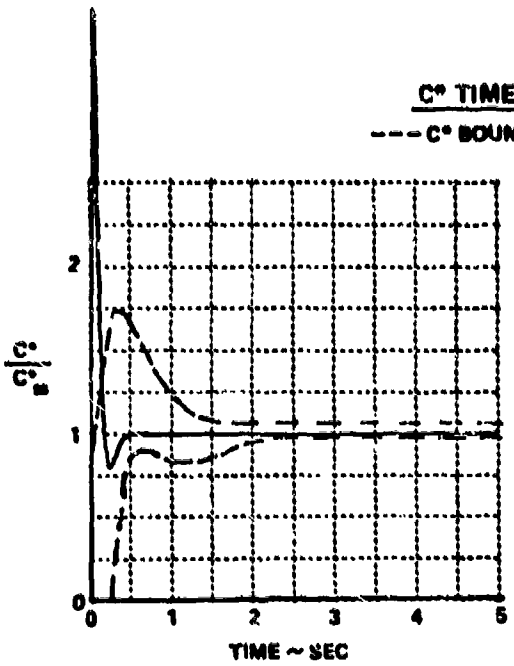
CONFIGURATION No. 7P

PR(PILOT M):

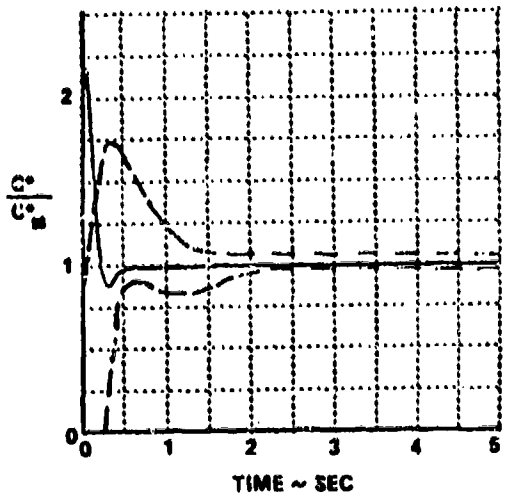
PR(PILOT W): 4

C* TIME HISTORIES

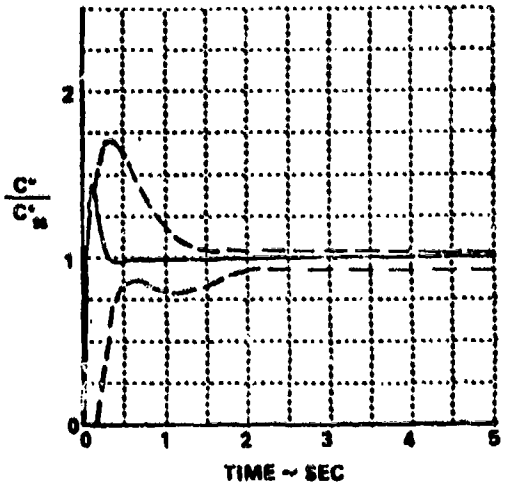
--- C* BOUNDARIES (PR = 3.5)



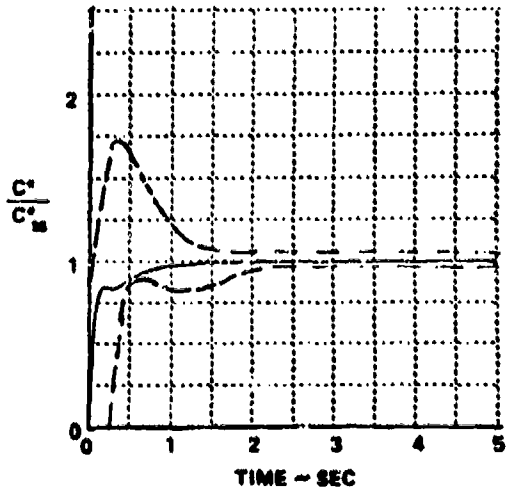
CONFIGURATION No. 8A PR(PILOT M): 5
PR(PILOT W): 4



CONFIGURATION No. 8B PR(PILOT M): 3.5
PR(PILOT W):



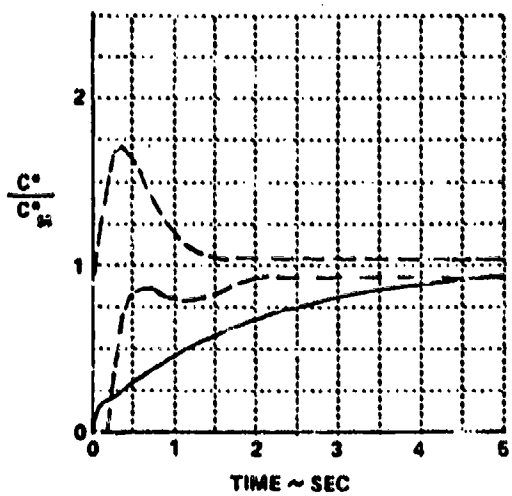
CONFIGURATION No. 8C PR(PILOT M): 3.5
PR(PILOT W): 3



CONFIGURATION No. 8D PR(PILOT M): 2
PR(PILOT W): 4

C* TIME HISTORIES

– – – C* BOUNDARIES (PR = 3.5)



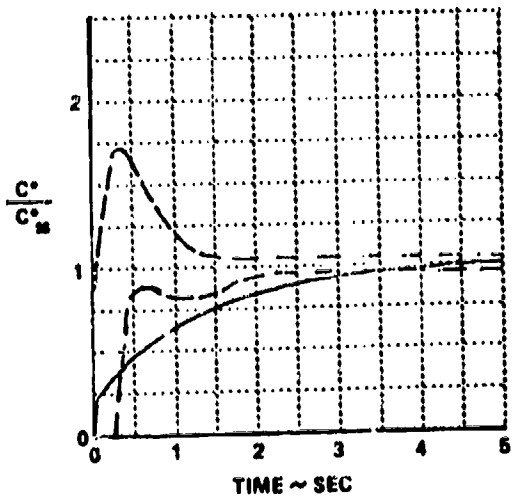
CONFIGURATION No. 8E

PR(PILOT M): 2.5, 3

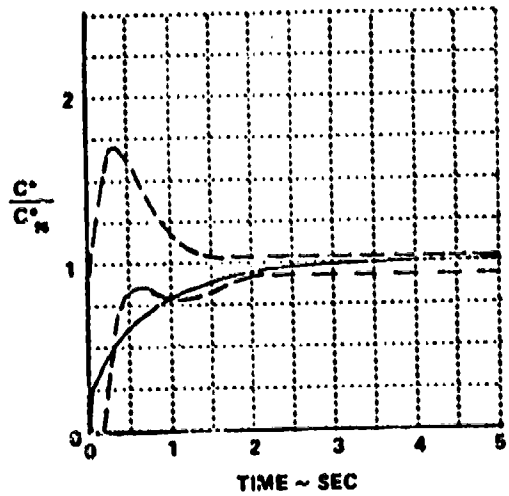
PR(PILOT W): 5

C* TIME HISTORIES

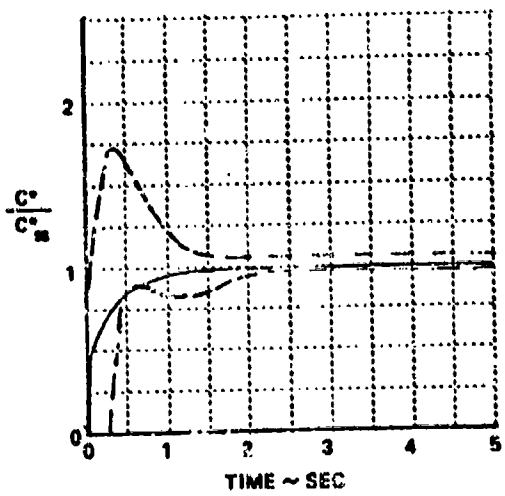
--- C* BOUNDARIES (PR = 3.5)



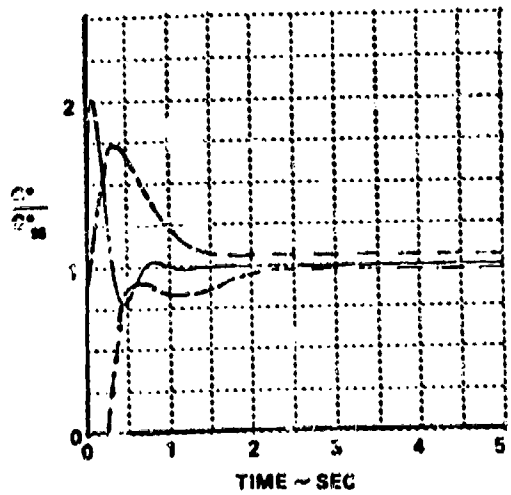
CONFIGURATION No. 9 PR(PILOT M): 5, 6
PR(PILOT W):



CONFIGURATION No. 10 PR(PILOT M): 4, 4
PR(PILOT W):



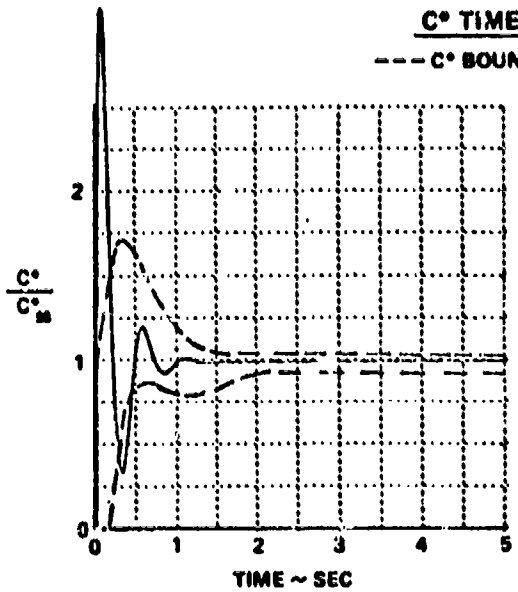
CONFIGURATION No. 11 PR(PILOT M): 2.5, 3
PR(PILOT W):



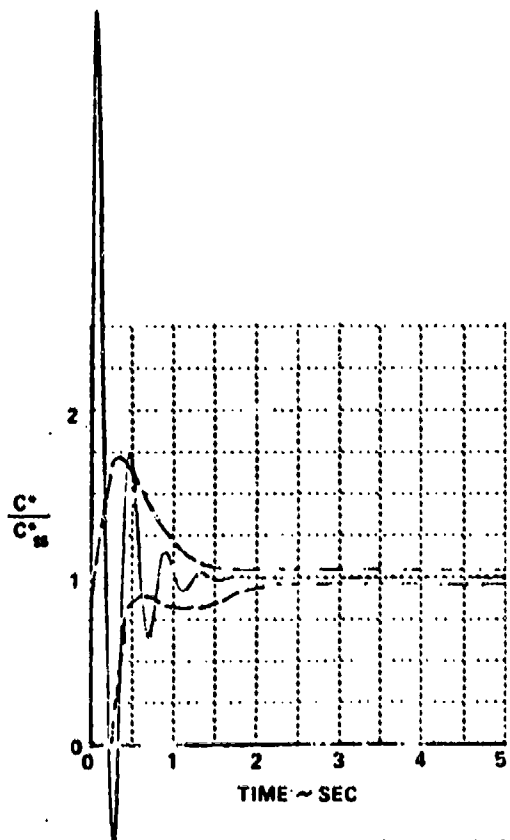
CONFIGURATION No. 12 PR(PILOT M): 5, 6
PR(PILOT W): 6

C* TIME HISTORIES

--- C* BOUNDARIES (PR = 3.5)



CONFIGURATION No. 13 PR(PILOT M): 7, 5.5
PR(PILOT W):



CONFIGURATION No. 14 PR(PILOT M): 4.5, 6
PR(PILOT W):

APPENDIX IV

LONGITUDINAL TRANSFER FUNCTIONS

In this appendix, several simplified longitudinal transfer functions are developed in support of the discussion in the text. The following equations of motion are used to represent the airplane for this purpose. They assume constant speed and neglect incremental effects of gravity.

$$\ddot{\theta} = M_q \dot{\theta} + M_{\dot{\alpha}} \dot{\alpha} + M_\alpha \alpha + M_{\delta_e} \delta_e$$

$$\dot{\alpha} = \dot{\theta} - L_\alpha \alpha - L_{\delta_e} \delta_e$$

$$n = \frac{V_T}{g} (\dot{\theta} - \dot{\alpha})$$

The equations imply that the reference axes are stability axes and that the wings are always level so that $\dot{\theta} = q$ and $\theta(s) = \frac{1}{s} \dot{\theta}(s)$. The variables θ , α , n , and δ_e are incremental values from the reference condition.

The following transfer functions in Laplace notation arise from the above equations:

$$\frac{\dot{\theta}}{\delta_e} = \frac{(M_{\delta_e} - L_{\delta_e} M_{\dot{\alpha}})s + (M_{\delta_e} L_\alpha - M_\alpha L_{\delta_e})}{s^2 + (L_\alpha - M_q - M_{\dot{\alpha}})s - (M_\alpha + M_q L_\alpha)}$$

$$\frac{\alpha}{\delta_e} = \frac{-L_{\delta_e} s + (M_{\delta_e} + M_q L_{\delta_e})}{s^2 + (L_\alpha - M_q - M_{\dot{\alpha}})s - (M_\alpha + M_q L_\alpha)}$$

$$\frac{n}{\delta_e} = \frac{V_T}{g} \frac{L_{\delta_e} s^2 + (-L_{\delta_e} M_q - L_{\delta_e} M_{\dot{\alpha}})s + (M_{\delta_e} L_\alpha - M_\alpha L_{\delta_e})}{s^2 + (L_\alpha - M_q - M_{\dot{\alpha}})s - (M_\alpha + M_q L_\alpha)}$$

Assuming that the product of small terms is negligible $(L_{\delta_e} M_q \approx L_{\delta_e} M_{\dot{\alpha}} \approx 0)$

$$\frac{\dot{\theta}}{\delta_e} = \frac{\left[M_{\delta_e} s + (M_{\delta_e} L_\alpha - M_\alpha L_{\delta_e})\right]}{s^2 + (L_\alpha - M_q - M_{\dot{\alpha}})s - (M_\alpha + M_q L_\alpha)}$$

$$\frac{\alpha}{\delta_e} = \frac{(-L_{\delta_e} s + M_{\delta_e})}{s^2 + (L_\alpha - M_q - M_{\dot{\alpha}})s - (M_\alpha + M_q L_\alpha)}$$

$$\frac{n}{\delta_e} = \frac{V_T}{g} \frac{\left[L_{\delta_e} s^2 + (M_{\delta_e} L_\alpha - M_\alpha L_{\delta_e})\right]}{s^2 + (L_\alpha - M_q - M_{\dot{\alpha}})s - (M_\alpha + M_q L_\alpha)}$$

The short-period natural frequency and damping ratio can be expressed as:

$$\omega_{sp}^2 = -M_\alpha - M_q L_\alpha$$

$$2\zeta_{sp}\omega_{sp} = L_\alpha - M_q - M_{\dot\alpha}$$

$$\zeta_{sp} = \frac{L_\alpha - M_q - M_{\dot\alpha}}{2\sqrt{-M_\alpha - M_q L_\alpha}}$$

and:

$$\frac{1}{\tau_{\theta_2}} = \frac{M_{\delta_e} L_\alpha - M_\alpha L_{\delta_e}}{M_{\delta_e}}$$

Making these substitutions and rearranging,

$$\frac{\dot\theta}{\delta_e} = \frac{M_{\delta_e}}{\omega_{sp}^2}\left(\frac{1}{\tau_{\theta_2}}\right)\frac{(\tau_{\theta_2}s+1)}{\left(\frac{s^2}{\omega_{sp}^2}+\frac{2\zeta_{sp}}{\omega_{sp}}s+1\right)}$$

$$\frac{\alpha}{\delta_e} = \frac{M_{\delta_e}}{\omega_{sp}^2}\frac{\left(-\frac{L_{\delta_e}}{M_{\delta_e}}s+1\right)}{\left(\frac{s^2}{\omega_{sp}^2}+\frac{2\zeta_{sp}}{\omega_{sp}}s+1\right)}$$

$$\frac{n}{\delta_e} = \frac{M_{\delta_e}}{\omega_{sp}^2}\left(\frac{V_T}{g}\frac{1}{\tau_{\theta_2}}\right)\frac{(\tau_{\theta_2}\cdot\frac{L_{\delta_e}}{M_{\delta_e}}s^2+1)}{\left(\frac{s^2}{\omega_{sp}^2}+\frac{2\zeta_{sp}}{\omega_{sp}}s+1\right)}$$

For most conventional airplanes, the numerator time constants in the $\frac{\alpha}{\delta_e}$ and $\frac{n}{\delta_e}$ transfer functions are negligible. However, for airplanes having a tail length which is quite short, these numerator terms can be important.

The following relationships can be derived from the above transfer functions:

(1) n/α :

For a step input,

$$\left(\frac{n}{\delta_e}\right)_{ss} = \left.\frac{n}{\delta_e}\right|_{s\to 0} = \frac{M_{\delta_e}}{\omega_{sp}^2}\left(\frac{V_T}{g}\frac{1}{\tau_{\theta_2}}\right)$$

$$\left(\frac{\alpha}{\delta_e}\right)_{ss} = \left.\frac{\alpha}{\delta_e}\right|_{s\to 0} = \frac{M_{\delta_e}}{\omega_{sp}^2}$$

therefore,

$$\frac{n}{\alpha} = \frac{(n/\delta_e)_{ss}}{(\alpha/\delta_e)_{ss}} = \frac{V_T}{g}\,\frac{1}{\tau_{\theta_2}}$$

(2) F_s/n :

$$\left(\frac{n}{F_s}\right)_{ss} = \left(\frac{n}{\delta_e}\right)_{ss}\left(\frac{\delta_e}{F_s}\right)_{ss}$$

and $M_{F_s} = M_{\delta_e}\left(\frac{\delta_e}{F_s}\right)_{ss}$

therefore, $\frac{F_s}{n} = \left(\frac{n}{F_s}\right)^{-1}_{ss} = \frac{\omega^2_{sp}}{M_{F_s}(n/\alpha)}$

(3) θ/F_s transfer function (negligible control system dynamics):

$$\frac{\theta}{F_s} = \frac{\theta}{\delta_e}\left(\frac{\delta_e}{F_s}\right)_{ss} = \frac{M_{F_s}}{\omega^2_{sp}}\left(\frac{1}{\tau_{\theta_2}}\right)\frac{(\tau_{\theta_2}s+1)}{s\left(\frac{s^2}{\omega^2_{sp}}+\frac{2\zeta_{sp}}{\omega_{sp}}s+1\right)}$$

or $$\frac{\theta}{F_s} = \frac{K_\theta(\tau_{\theta_2}s+1)}{s\left(\frac{s^2}{\omega^2_{sp}}+\frac{2\zeta_{sp}}{\omega_{sp}}s+1\right)}$$

where $$K_\theta = \frac{M_{F_s}}{\omega^2_{sp}\,\tau_{\theta_2}} = \frac{g}{V_T(F_s/n)}$$

Note that K_θ as defined above is the same as the steady-state value of $\dot{\theta}/F_s$.

(4) $\left|\ddot{\theta}/F_s\right|_{max}$ (negligible control-system dynamics):

$$\frac{\ddot{\theta}}{F_s} = s^2 \frac{\theta}{F_s} = K_\theta \frac{s(\tau_{\theta_2} s + 1)}{\left(\frac{s^2}{\omega_{sp}^2} + \frac{2\zeta_{sp}}{\omega_{sp}} s + 1\right)}$$

For $\zeta_{sp} > 0.7$, and $1/\tau_{\theta_2} \leq \omega_{sp}$,

$$\left|\frac{\ddot{\theta}}{F_s}\right|_{max} = \left|\frac{\theta}{F_s}\right|_{\omega \to \omega} = K_\theta \tau_{\theta_2} \omega_{sp}^2$$

Substituting expression for K_θ,

$$\left|\frac{\ddot{\theta}}{F_s}\right|_{max} = \frac{\omega_{sp}^2}{\left(\frac{W_T}{g}\frac{1}{\tau_{\theta_2}}\right)\left(\frac{F_s}{W}\right)} = \frac{\omega_{sp}^2}{\left(\frac{n}{e}\right)\left(\frac{F_s}{n}\right)} \qquad (\zeta_{sp} > 0.7)$$

APPENDIX V

DETAILS OF SIMULATION MECHANIZATION AND DATA REDUCTION TECHNIQUES

This in-flight experiment was performed in the three-axis variable-stability T-33 airplane, modified and operated by CAL for the USAF. The desired FCS dynamics were simulated by altering the T-33 control system with suitable electronic circuits. The variable-stability response-feedback system of the T-33 was used to simulate the desired airplane dynamics. The mechanization of the airplane plus control-system longitudinal dynamics for this experiment is summarized in Figure V-1 using constant-speed airplane dynamics.

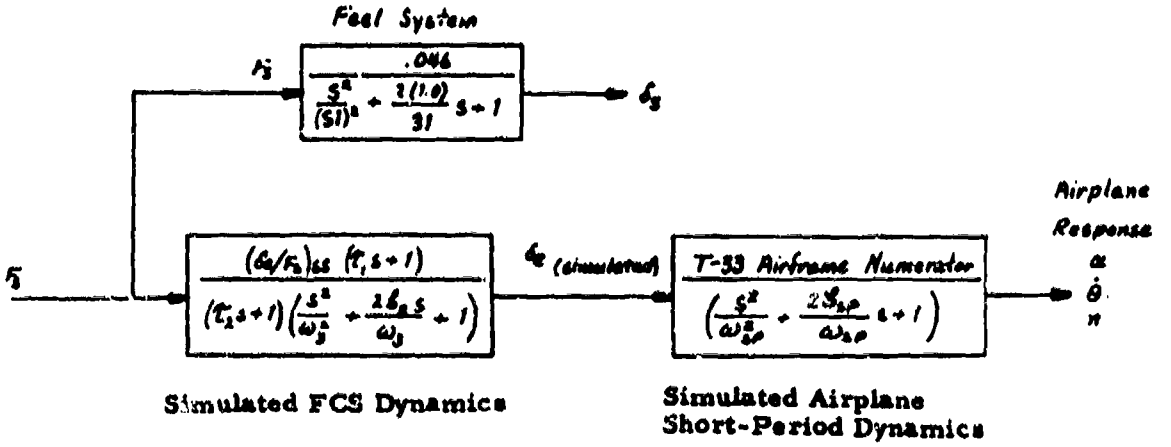
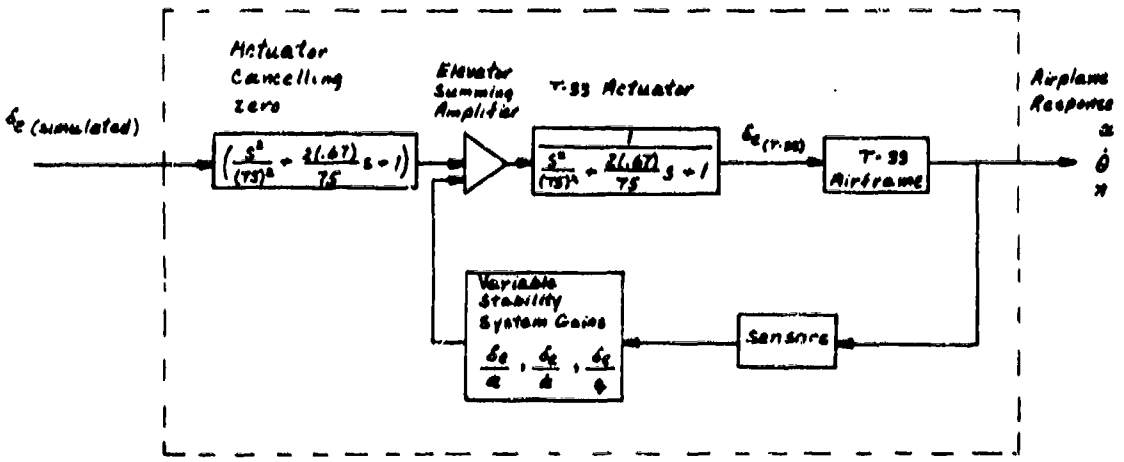


Figure V-1 Mechanization of Airplane plus FCS Longitudinal Dynamics.

The feel system characteristics shown in Figure V-1 were mechanized using an electro-hydraulic feel servo, with position and rate feedbacks to control the frequency and damping. Experimental frequency responses of the feel system, obtained during ground calibrations, show that the dynamic characteristics presented in the figure approximate the measured phase within 2 degrees and the measured amplitude within 5%, for frequencies as high as 30 rad/sec. Electronic circuit cards, designed to represent the desired FCS dynamics, were carried in the nose of the T-33 and could be selected by the safety pilot for each evaluation. Experimental frequency

responses of these circuits show near perfect correlation of amplitude and phase with the FCS transfer functions used in this report, for frequencies as high as 60 rad/sec.

The desired short-period dynamics were achieved by feeding back α , $\dot{\alpha}$ and q signals to the T-33 elevator actuator with the appropriate feedback gains. It is important to remember that because response feedbacks are used, the numerators of the longitudinal transfer functions remain those of the T-33 airframe. Figure V-2 shows a simplified block diagram of the mechanization for the airplane dynamics.



Simulated Airplane Short-Period Dynamics

Figure V-2 Mechanization of Airplane Longitudinal Dynamics

The circuit cards for simulating the FCS dynamics all contained a second-order zero (shown in Figure V-2) designed to cancel the T-33 actuator dynamics. With the response-feedback loops closed, the T-33 actuator roots will migrate somewhat; but since the roots are at high frequency, the

movement will be small. The T-33 actuator can therefore be considered cancelled by the second-order zero, as far as the airplane's response to F_s inputs is concerned. For the configurations evaluated with $\frac{1}{\tau_1} = \frac{1}{\tau_2} = \infty$, the force command signal went directly to the elevator summing amplifier. In these cases the (ω_y , ζ_y) dynamics were those of the T-33 actuator. The six additional short-period configurations (9 to 14) simulated in this experiment had the feel system dynamics in series with the simulated airplane plus T-33 actuator.

The lateral-directional characteristics simulated in this experiment were achieved using the appropriate response-feedback gains in a manner analogous to the longitudinal characteristics. The rudder and aileron feel system were in series with the simulated airplane so that position commands went to the control surface actuators.

The feedback gains required to achieve the desired airplane short-period dynamics were determined during the calibration phase of the flight program. During the evaluation phase, calibration records were taken of each configuration evaluated in order to identify ω_{sp} , ζ_{sp} , n/α and the selected F_s/n . To determine ω_{sp} and ζ_{sp} , in-flight recordings of either $\dot{\theta}$ or α to a manual elevator doublet were analog-matched. This method proved to be both accurate and repeatable. Records of the airplane's α and n response to a series of automatic electrical steps (fed directly to the elevator summing amplifier) were used to determine n/α and F_s/n . To obtain F_s/n from these records, the measured value of $(n/\delta_e)_{ss}$ was combined with the value of $(\delta_e/F_s)_{ss}$ gain selected by the pilot. Several F_s/n measurements using out-of-trim manual elevator steps were taken to confirm the accuracy of the above technique.

The values of ω_{sp} and ζ_{sp} used in this report represent the average values determined from the calibration records for all the evaluations of that configuration. The maximum variations from these average values of ω_{sp} and ζ_{sp} , measured in the course of the experiment, were $\pm$ 10% for ω_{sp} and $\pm$ 5% for ζ_{sp} . The values of n/α and F_s/n used in this report similarly involved the use of averaged calibration data, and the maximum variations from the averages were $\pm$ 10% for both n/α and F_s/n .

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13 ABSTRACT

The effects of control system dynamics on the longitudinal flying qualities of fighter airplanes were investigated in flight, using the USAF/CAL variable stability T-33 airplane. Two pilots evaluated a total of 57 different combinations of control system and short-period dynamics at two flight conditions, while performing tasks representative of the "combat" phase of a fighter's mission. The pilot rating and comment data from this investigation indicate that the dynamic modes of the flight control system can cause serious flying qualities problems, even if the short-period mode is well behaved. The data do not correlate with the control system requirements of MIL-F-8785B. In addition, the data demonstrate that the C* criterion does not adequately account for the effects of control system dynamics. Pilot-in-the-loop analysis of the data is shown to describe effectively the pilot's difficulties in control of pitch attitude, providing insight into how the pilot flies the airplane. A design criterion, based on this analysis, is shown to be applicable to a wide range of short-period and control system dynamics. A simplified version is also presented to provide the designer with preliminary estimates of flying qualities. Volume I contains the body of the report, while Volume II consists of the Appendices.

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